Biodiversity impacts at various scales following conservation management of synanthropic sites in North West England.

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Biodiversity impacts at various scales following conservation management of synanthropic sites in North West England.

Abstract

Large areas of ex-industrial land remained following the decline and abandonment of heavy industries from the 1960s onwards. While most sites were developed, a few escaped significant modification and succession upon nutrient poor soils produced species-rich plant and invertebrate assemblages. One of the largest such sites is the Wigan Flashes area in North West England which now comprises part of the 1500ha Wigan Greenheart. This contains a variety of habitats including open water, extensive reed beds, grasslands scrub and woodland. It is also home to several rare species. In the last two decades, work has been undertaken to improve the conservation value of these habitats.

This thesis addresses a number of questions assessing the contribution that synanthropic sites can make to nature conservation. Within the last eighteen years, conservation work in the Wigan Greenheart area has progressed from single site-based projects to a landscape scale-approach. In the first chapter, the potential of this approach is explored by assessing to what extent the separate reedbed habitats within the area are functioning as a single unit based upon the dispersal distances and breeding area requirements of reedbed specialist species. This showed that for many vertebrates the reedbeds may function as a unit, however for the invertebrates not enough is known of the ecological requirements and dispersal capacity to determine whether the habitats function as a network.

The second study investigates the success of management interventions in a twenty-year grassland creation project. By targeting the management and steering the grassland development by the addition of Yellow Rattle, *Rhinanthus minor* L., the meadows have

developed into recognisable plant communities, comparable to vegetation described for long established grasslands managed in a similar manner. The third study assesses the importance of secondary woodland for the fast-declining Willow Tit (*Poecile montanus* Conrad von Baldenstein, 1827). The connectivity provided by the network of scrub habitats and secondary woodlands is a key factor in the continued success of Willow Tit in the area. The final chapter explores the evolutionary dynamics of such disturbed sites. Utilising a morphometric approach an assessment of the marsh orchid (*Dactylorrhiza* spp.) populations was undertaken. This revealed extensive hybridisation between southern and northern marsh orchids (*Dactylorrhiza praetermissa (Druce) Soó* and *Dactylorrhiza purpurella (T and T.A. Stephenson) Soó*) on the ex-industrial habitats within the narrow contact zone between these two species, thus revealing the dynamic evolutionary processes at play in these habitats. Hybridization is a method by which genes are transferred from one species to another typically between closely related species. This potential source of genetic novelty may be an important source of variation and allow plants in novel habitats or changing environments to adapt to their conditions.

The thesis has provided evidence that the management of these synanthropic sites can provide nationally important conservation outcomes over a 16-year time-scale, benefiting a range of habitats, species and communities. The development of the reedbeds and the meadows demonstrates the capacity of the post-industrial landscape to support communities of conservation value.

Refer to Table 1 for acronyms and abbreviations used throughout this thesis

Table 1. Table of Acronyms and abbreviations used.

Acronym	Explanation
BAP	Biodiversity Action Plan
BTO	British Trust for Ornithology
CCA	Canonical Correspondence Analysis
DBH	Diameter at Breast Height
GIS	Geographic Information System
GMEU	Greater Manchester Ecology Unit
GPS	Global Positioning System
LHS	Local Heritage Site
LNR	Local Nature Reserve
LWT	Lancashire Wildlife Trust
MAVIS	Modular Analysis of Vegetation Information System
MBC	Metropolitan Borough Council
NE	Natural England
NGO	Non-Governmental Organisation
NIA	Nature Improvement Area
NMDS	Non-metric multi-dimensional scaling
NVC	National Vegetation Classification
PCA	Principal Component Analysis
PFA	Pulverised Fuel Ash
RSPB	Royal Society for the Protection of Birds
SAC	Special Area of Conservation
SSSI	Site of Special Scientific Interest
UK	United Kingdom
WoS	Web of Science

Chapter 1 - Introduction

Following the Industrial Revolution, Britain became a heavily industrialised country. The availability of raw materials, predominantly coal, led to extensive industrialisation in areas such as the North East, Yorkshire, Lancashire, parts of the Midlands and South Wales. Following the decline of these industries from the 1960s onwards, large areas of ex-industrial land were abandoned. Some of these were redeveloped for building, others were treated with top soil and planted to produce 'country park' type areas, while others remained undeveloped. Within the north-west of England much of the industrial dereliction left after c.1960 was treated by Lancashire County Council, Greater Manchester Joint Reclamation Team and Wigan Council with varying degrees of success. One of the problems with derelict land reclamation was to determine a realistic objective. To reclaim land for agricultural use required a great deal of work and expense for remediation (Wigan Council 2004). Consequently, a few escaped development or significant modification. The subsequent succession upon nutrient-poor soils produced markedly species-rich plant and invertebrate assemblages (Shaw, 1995). The term 'synanthropic' is often used for these habitats meaning accompanying and aided by humans on sites heavily disturbed by human activity (Kent *et a*l, 1999).

The Ratcliffe Criteria, first listed in Nature Conservation Review of; size, diversity, naturalness, rarity, fragility, typicalness, recorded history, position in an ecological/geographical unit, potential value and intrinsic appeal (Ratcliffe, 1977), are a widely accepted method to assess whether a site has conservation value. Ex-industrial sites typically meet three of the ten criteria: size, diversity and potential. However, Ratcliffe's (1977) list of 722 sites worthy of statutory protection in the UK almost completely omitted ex-industrial sites, possibly because they were perceived to fall short of the other seven criteria: fragility, naturalness, rarity, position within the ecological or geographical unit, typicalness, recorded history and intrinsic appeal. Despite this omission, in the last 40 years the value of such sites for the conservation of biodiversity has been recognised (Greenwood and Gemmill, 1978; Shaw, 1994, 2003).

Following revision of the Ratcliffe Criteria (Ratcliffe, 1989; Bainbridge *et al.*, 2013) SSSI (Site of Special Scientific Interest) status has been awarded to many ex-industrial sites. This includes Abram Flashes SSSI (notified 1990) and Bryn Marsh and Ince Moss SSSI (notified 1989), both sites included in the study area of this thesis.

The term biodiversity has been coined that aims to describe the diversity of form, the variation and function in the natural world created by evolution. The term biodiversity says much more than a simple statement that there are millions of different kinds of organisms, because biological diversity exists at many different levels, from global down to the very small (Wilson 1992)

Biodiversity has been defined by the United Nations as variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Convention on Biological Diversity, 1993). The broad-scale spatial variation in biodiversity has been recognised (Gaston 2000) when investigating latitudinal gradients in species richness, species–energy relationships, relationships between local and regional richness and taxonomic covariance within the species richness. A substantial proportion of variation in species richness can be explained in terms of a few environmental variables, these rates in turn are determined by the effects of abiotic and biotic factors (the latter may be intrinsic or extrinsic to the organisms or habitats of concern) acting at different ecological scales.

Recognition of the biodiversity value of such synanthropic sites has sometimes led to statutory protection; for instance, the restored mining subsidence and spoil tips at Fairburn and Swillington Ings SSSIs in Yorkshire are notified for their wetland flora and wading bird

populations (Bell and Donnelly, 2006), Rixton Clay Pits SSSI (Cheshire) is notified for its flora and population of Great Crested Newt (*Triturus cristatus* Linnaeus, 1758) and Nob End SSSI (Greater Manchester), a former chemical waste site, is notified for its calcareous flora. The Dearne Valley, a former coal mining area akin to Wigan is now designated as an NIA (Nature Improvement Area). These all demonstrate that successful conservation of synanthropic habitats occurs when they are viewed in the context of the landscape in which they are situated, rather than viewing them as individual problems (Ling *et al*., 2007).

One of the largest synanthropic sites in the UK is the Wigan Flashes area in Greater Manchester, North West England. This comprises the Bryn Marsh and Ince Moss SSSI and surrounding land that lies south west of Wigan, broadly bounded by the London-Glasgow and Wigan-Liverpool railway lines and the Leeds-Liverpool canal (see figure 1.1.).

Figure 1.1. Map of the Wigan Flashes Local Nature Reserve, showing major wetland habitats and open water.

In the North-west of England, as elsewhere, the exploitation of coal and peat during the Industrial Revolution alongside the development of textile, iron and steel industries, had a major impact upon the wider landscape. This left behind a physically scarred landscape that was characterised by patches of habitat. A programme of land restoration in Wigan commenced in the late 1970s, led by the local authority. This chiefly involved landscaping and planting of much of the colliery spoil in the area. Recognition of the conservation value of part of the area came with SSSI notification of the Flashes in 1989 and 1990. This was followed with a further large part of the Wigan Flashes SSSI being purchased from RailTrack in 1998 by Wigan MBC (Metropolitan Borough Council), to be managed for conservation jointly by the council and the Lancashire Wildlife Trust. Since this purchase the council and the Wildlife Trust have acquired and developed other landholdings in the area with an intention to manage the area in an integrated manner for conservation and recreation. This is known as the Wigan Greenheart area (Figure 1.2). This is a 1500ha network of sites that has been heavily modified by industrial processes, in the last two centuries to leave a variety of habitats. These are dominated by subsidence lakes (flashes) that consist of open water and extensive reedbeds, grasslands, scrub and woodland. In addition to the Bryn Marsh and Ince Moss SSSIs, it also includes the SSSIs at Abram Flashes plus the Local Nature Reserve at Pennington Flash (see Table 1.1).

Although dominated by mining and peat winning, the wetlands have also been tipped with a range of waste materials, including colliery shale, pulverised fuel ash (PFA) and boiler ash. Other important habitats within the Greater Manchester area include the reedbeds found at the silt lagoons at Woolston Eyes and the clay pits at Rixton, with their important numbers of Great Crested Newts. In the last decade this network of site across Greater Manchester and parts of Lancashire and Cheshire have been designated as the Greater Manchester Wetlands Nature Improvement Area (Figure 1.3).

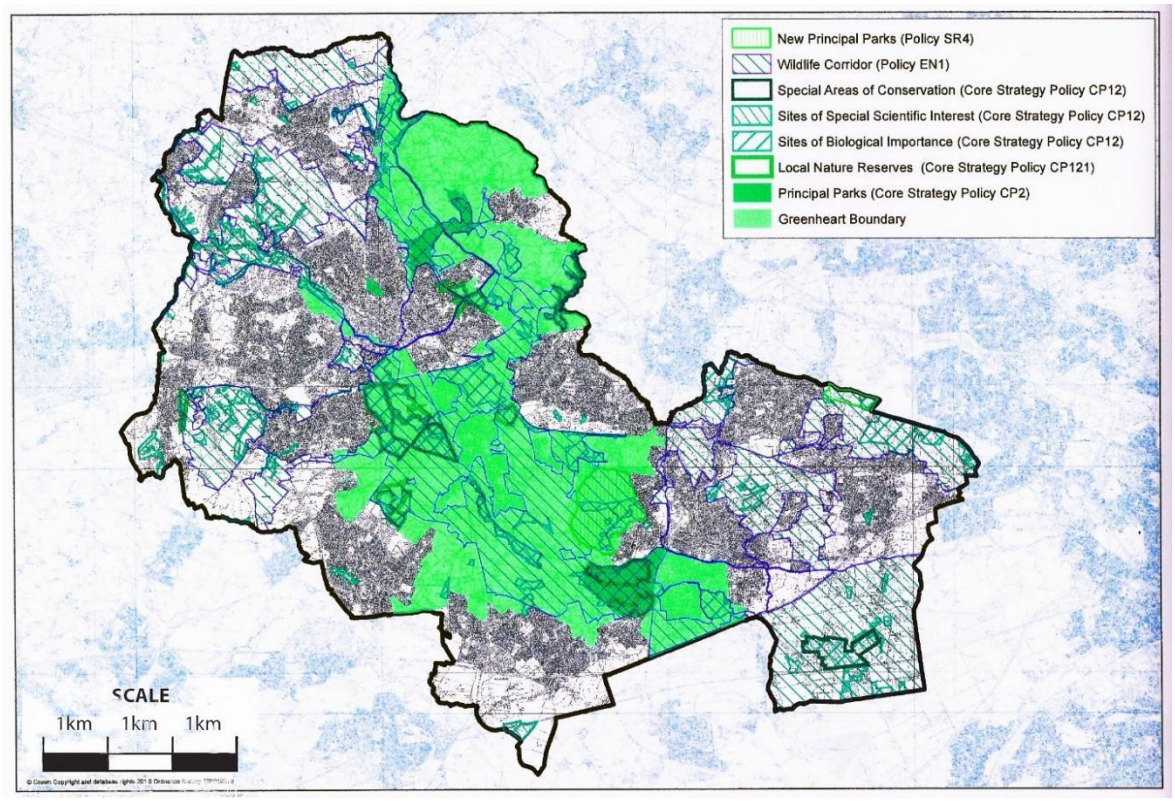

Figure 1.2. Greenheart regional Park (courtesy of Wigan Council, 2018), Locating the key greenspaces, within Wigan Council's countryside strategy.

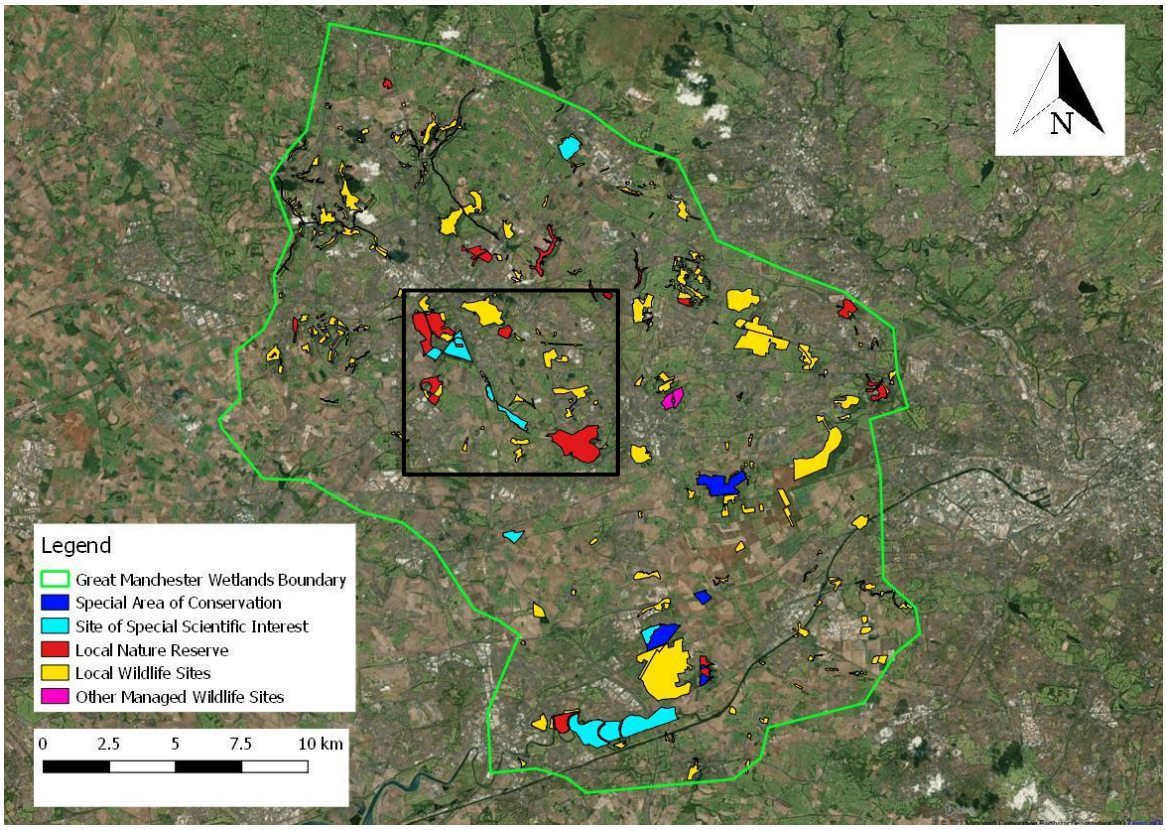

Figure 1.3. Map of the Great Manchester Wetlands NIA area, showing locations of the main nature reserves. The boxed area encloses the region in Fig 1.2 above.

In the last nineteen years, work has been undertaken to improve the conservation value of these habitats. While the size and diversity of the sites represents a considerable conservation asset in itself, the area contains some notable habitats. These include the reedbed, grasslands, peatlands, lowland fen and floodplain grazing marsh with areas of wet deciduous woodland scattered in between. The initial conservation work was targeted at the Bittern (*Botaurus stellaris* Linnaeus, 1758), although the requirements of other species were incorporated into the habitat restoration. These species included avian wetland specialists and the Water Vole (*Arvicola amphibious* Linnaeus, 1758). The conservation work involved major earthworks to unify the habitats, including linking the hydrology, reedbed lowering, ditch creation, and habitat creation to allow the reedbed habitats to form a cohesive wetland across the parts of the project area. The management has led to the improvement of the general quality of the habitat compared with the starting point and an increase in the main target species (Champion and Ashton, 2011).

Table 1.1. Protected sites in Great Manchester Wetlands NIA at April 2018, showing site designations and features mentioned in the designation. Green highlight indicates sites that are predominantly semi-natural, orange highlight indicates predominantly ex-industrial sites. SAC (Special Area of Conservation); LNR (Local Nature Reserve); LHS (Local Heritage Site); LWT (Lancashire Wildlife Trust).

Site Name	Grid Reference	Area Ha	Site Grade	District	Features
Astley & Bedford Moss	SJ692975	102.3	SAC	Wigan	Bog & birds
Risley Moss	SJ669918	275.0	SAC	Warrington	Bog & woodland
Rixton Clay Pits	SJ742937	20.0	SAC	Warrington	Amphibians & grassland
Abram Flashes	SD612002	42.8	SSSI	Wigan	Reedbed & birds
Highfield Moss	SJ614956	18.2	SSSI	Wigan	Valley mire & grassland
Red Moss	SD635100	78.5	SSSI	Bolton	Bog, dragonflies & birds
Woolston eyes	SJ647880	70.0	SSSI	Warrington	Fen, open water & birds
Pennington Flash	SJ635990	205.0	SSSI/LNR	Wigan	Grassland, reedbed, fen, water, birds
Wigan Flashes	SD581028	242.0	SSSI/LNR	Wigan	Reedbeds, swamp, open water & birds
Borsdane Wood	SD626062	37.2	LNR	Wigan	Ancient woodland, fungi & birds
Kirkless	SD603061	21.2	LNR	Wigan	Calcareous grassland & ponds
Orrell Water Park	SD532032	3.5	LNR	Wigan	Ponds, lodges, open water & birds
Three Sisters	SD584010	28.2	LNR	Wigan	Grassland & wood
Low Hall Park	SD612033	9.2	LNR	Wigan	Reedbed, fen, open water & birds
Paddington Meadows	SJ 631886	34.4	LNR	Warrington	Meadow & wet woodland
Low Hall Park	SD612033	17.2	LNR	Wigan	Fen & woodland
Three Sisters	SD584010	21.7	LNR	Wigan	Ponds, grassland, woodland & birds
Abbey Lakes	SD526047	16.9	LHS	Wigan	Woodland & open water
Ackhurst Lane Sand pit	SD542070	20.3	LHS	Wigan	Urban
Alder Forest Marsh	SJ748996	14.5	LHS	Salford	Woodland
Altrincham Sewage Works	SJ753909	10.2	LHS	Trafford	Swamp & birds
Amberswood Common	SD605040	98.7	LHS	Wigan	Grasslands, birds & ponds

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Site Name	Grid Reference	Area Ha	Site Grade	District	Features
Arley Woods	SD585107	14.9	LHS	Wigan	Woodland
Ashton Sewage Works	SJ768932	7..0	LHS	Trafford	Habitat mosaic
Astley Green	SJ704996	9.5	Community	Wigan	Grassland
Atherton & Bedford Woods	SD671012	24.6	LHS	Wigan	Ancient woodland
Barlows Farm	SD627023	23.3	LHS	Wigan	Woodland
Barrowcroft Wood	SD570106	8.1	LHS	Wigan	Woodland & aquatic invertebrates
Barton Clough	SD544007	2.0	LHS	Wigan	Ancient woodland
Bedford Colliery	SD672005	26.7	LWT Manchester	Wigan	Grassland
Bewdsey Tip	SJ552894	11.9	LHS	Warrington	Grassland
Bibi's Sand Pit	SD573118	1.5	LHS	Wigan	Ponds
Bickershaw	SD637009	250.0	LHS	Wigan	Grassland & birds
Birchmoss Covert	SJ749909	6.1	LHS	Trafford	Woodland
Bispham Hall Woods	SD525024	25.9	LHS	Wigan	Woodland
Bittern Pits Wood	SD739000	4.6	LHS	Salford	Woodland
Blackleach Reservoir	SD739040	24.7	LHS	Salford	Scrub, open water & birds
Blundell's Wood	SD557035	4.5	LHS	Wigan	Woodland
Botany Bay	SD628063	162.9	LHS	Salford	Woodland & birds
Brickfield Wood	SD731018	2.5	LHS	Salford	Woodland & ponds
Bridgewater Canal	SJ763994	3.1	LHS	Salford	Canal
Broadoak Wood	SJ725909	3.7	LHS	Trafford	Woodland
Calico Meadow	SD536090	0.69	LHS	Wigan	Grassland
Callico & Hullet Hole Wood	SD537093	14.8	LHS	Wigan	Woodland
Carr Brook Mire	SD684042	0.6	LHS	Bolton	Marsh
Carrington Power Station	SJ728930	3.3	LHS	Trafford	Habitat mosaic
Chat Moss Remnants	SJ700965	34.9	LHS	Wigan	Bog

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Site Name	Grid Reference	Area Ha	Site Grade	District	Features
Clifton Moss (South)	SD764033	17.9	LHS	Salford	Woodland, scrub, fen & ponds
Coroners Wood	SJ706907	1.9	LHS	Trafford	Ancient woodland
Cow Lee Brook	SD658068	3.7	LHS	Bolton	Grassland
Croft Grasslands	SJ666837	2.9	LHS	Warrington	Grassland
Crooke	SD552072	13.7	LHS	Wigan	Grassland, swamp & birds
Crooke West Clay Pits	SD546071	1.6	LHS	Wigan	Ponds, grassland
Crown Clough	SD632116	0.5	LHS	Bolton	Woodland
Culvert & Lodge at Standish	SD580101	1.2	LHS	Wigan	Bats
Cunningham Brook	SD643049	4.0	LHS	Bolton	Woodland
Damhouse Wood	SD699007	20.9	LHS	Wigan	Plantation woodland
Eatock Lodge	SD649046	5.8	LHS	Bolton	Ponds, amphibians & grassland
Edge Green	SJ602997	1.1	LHS	Wigan	Reedbeds, swamp & fen
Edge Lane Common	SJ595990	4.5	LHS	Wigan	Bog
Eleven Acre Common	SJ659947	4.4	LHS	Warrington	Grassland
Fairclough Wood	SD581095	3.6	LHS	Wigan	Ancient woodland
Fairhurst Lane	SD573095	2.9	LHS	Wigan	Woodland, amphibians & ponds
Field by Scowcroft Farm	SD629032	1.0	LHS	Wigan	Grassland
Firs Park	SD645006	2.2	LHS	Wigan	Open water
Flixton Sludge Beds	SJ735937	6.9	LHS	Trafford	Swamp & birds
Follient Wood	SD554077	3.1	LHS	Wigan	Ancient woodland
Foxhill Glen	SJ740970	0.8	LHS	Salford	Grassland
Gathurst – meadows	SD544074	3.2	LHS	Wigan	Habitat mosaics
Gemini Washlands	SJ595915	6.8	LHS	Warrington	Wet Grassland & scrub
Glead Wood & Tan Pit Slip	SD553022	8.4	LHS	Wigan	Woodland
Gorse Covert Mounds	SJ6684929	19.3	LHS	Warrington	Wet woodland
Grammar Ponds	SD623032	2.0	LHS	Wigan	Ponds

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Site Name	Grid Reference	Area Ha	Site Grade	District	Features
Grappenhall Heys	SJ636822	11.0	LHS	Warrington	Grassland & wetland
Great Woolden Wood	SJ693939	5.7	LHS	Salford	Woodland
Greaves Woods	SD544076	23.7	LHS	Wigan	Ancient woodland, ponds, bats & birds
Hall Lee Bank Park	SD662055	10.6	LHS	Bolton	Woodland
Hart Common	SD636054	2.7	LHS	Bolton	Ponds
High Rid Reservoir	SD667102	12.7	LHS	Bolton	Open water & winter birds
Hindley Deep Pits	SD616053	8.3	LHS	Wigan	Ponds
Hope Carr Nature Reserve	SJ661987	30.8	LHS	Wigan	Birds
How Clough	SD749028	3.5	LHS	Salford	Woodland
Hulton Park	SD679054	45.7	LHS	Bolton	Woodland ponds
Jack Lane	SJ733939	3.5	LHS	Trafford	Reedbed, swamp & birds
John Pit Woods	SD552086	46..5	LHS	Wigan	Ancient woodland & open mosaic habitat
Junction 6 – M61	SD639087	0.9	LHS	Bolton	Grassland
Lawns Wood	SD551077	5.3	LHS	Wigan	Woodland & birds
Leeds & Liverpool Canal	SD589106	38.7	LHS	Wigan	Canal
Lightshaw Lime Beds	SJ615988	8.5	LHS	Wigan	Ponds, open water & birds
Little Cannel Pit	SD626082	3.6	LHS	Bolton	Plantation & bryophytes
Lostock Crocus Sites	SD673082	0.6	LHS	Bolton	Grassland
Lostock Hall Mire	SD657088	0.9	LHS	Bolton	Swamp, pond & amphibians
Marsh at Lower Green	SJ703991	3.4	LHS	Wigan	Reedbed, swamp, open water & birds
Martland Heath	SD563064	6.6	LHS	Wigan	Swamp, heathland & ponds
Martland's Wood	SD539076	1.9	LHS	Wigan	Ancient woodland
Middle Brook Sidings	SD658085	8.8	LHS	Bolton	Grassland, reedbed & swamp
Middle Wood	SD740005	27.0	LHS	Salford	Plantation woodland
Mill Dam Wood	SD684046	11.9	LHS	Bolton	Woodland & open water
Mount Tabor	SJ614964	3.2	community	Wigan	Grassland

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Site Name	Grid Reference	Area Ha	Site Grade	District	Features
Moss Wood	SD536028	23.2	LHS	Wigan	Plantation woodland
New Cut	SJ633889	7.9	LHS	Warrington	Wet woodland
New Park Wood	SD678045	23.3	LHS	Bolton	Ancient woodland & plantation woodland
Old Hall Clough	SD670096	4.1`	LHS	Bolton	Woodland
Old River Irwell	SJ724941	4.1	LHS	Salford	Open water & woodland
Orrell Brickworks	SD535038	5.9	LHS	Wigan	Grassland & urban
Park Lane Colliery	SD617007	9.4	LHS	Wigan	Grassland
Parson's Meadow	SD571047	5.4	LHS	Wigan	Open water & grassland
Partington Nature Reserve	SJ702919	7.3	LHS	Trafford	Open water & habitat mosaic
Pestfurlong	SJ669929	39	LHS	Warrington	Moss & grassland
Platt Bridge Heath	SD616030	3.2	LHS	Wigan	Heathland
Pond at Four Gates	SD642077	1.5	LHS	Bolton	Pond, Great Crested Newt
Ponds at Primrose Lane	SD557105	1.5	LHS	Wigan	Ponds & amphibians
Ponds at Robin Hill Farm	SD549109	1.2	LHS	Wigan	Ponds, amphibians & aquatic invertebrates
Ponds Cleworth Hall)	SD705027	39.3	LHS	Wigan	Ponds
Ponds Langtree Lane	SD558108	4.2	LHS	Wigan	Ponds, grassland & amphibians
Ponds near Lightshaw Lane	SJ616991	11.7	LHS	Wigan	Ponds, amphibians, grassland & birds
Ponds near Lomax Brow	SD700044	76.6	LHS	Bolton	Ponds & amphibians
Ponds New Manchester	SD723023	17.6	LHS	Wigan	Ponds, amphibians & grassland
Porter's Wood	SD545067	7.7	LHS	Wigan	Ancient woodland
Railway Chew Moor	SD666076	5.1	LHS	Bolton	Habitat mosaic
Red Rock Railway Cutting	SD586102	9.0	LHS	Wigan	Woodland
Reedbeds at Shakerley	SD689036	0.6	LHS	Wigan	Grassland

Table 1.1. Protected sites in Great Manchester Wetlands NIA at April 2018, showing site designations and features mentioned in the designation. Green highlight indicates sites that are predominantly semi-natural, orange highlight indicates predominantly ex-industrial sites. SAC (Special Area of Conservation); LNR (Local Nature Reserve); LHS (Local Heritage Site); LWT (Lancashire Wildlife Trust).

Site Name	Grid Reference	Area Ha	Site Grade	District	Features
Regents Park Golf Course	SD667088	3.0	LHS	Bolton	Woodland, ponds & amphibians
River Mersey	SJ686904	45.7	LHS	Salford	Running water
Road Cutting on A6027	SD649093	0.8	LHS	Bolton	Grassland
Rumworth Lodge	SD677078	24.3	LHS	Bolton	Reedbeds, swamp & open water
Sankey	SJ595914	10.9	LHS	Warrington	Wetlands
Scot Lane Pond	SD561065	2.5	LHS	Wigan	Ponds
Sinderland Green Wood	SJ733905	2.9	LHS	Trafford	Woodland & ponds
Skitters Wood	SJ570994	6.7	LHS	Wigan	Woodland
Smithy Brook	SD570038	0.7	LHS	Wigan	Water Vole
Springside Reservoirs	SD743032	1.3	LHS	Salford	Pond
The Twiggeries	SJ624885	21.4	LHS	Warrington	Grassland & wet woodland
Towns Gate Lake & Marsh	SJ728949	1.4	LHS	Salford	Ponds & grasslands
Twelve Yards Road	SJ715970	14.5	LHS	Salford	Bog & birds
Tyldesley Sewage Works	SJ694989	3.0	LHS	Wigan	Scrub
Walkden Reservoir	SD744027	1.6	LHS	Salford	Ponds
Westy Point	SJ627886	4.8	LHS	Warrington	Grassland & scrub
Carrington Moss	SJ746919	1.4	LHS	Trafford	Woodland, reedbed, swamp, fen & birds
Wetland at Hindley Green	SD632022	7.4	LHS	Wigan	Ponds, amphibians & reedbed
Wetland by M6	SD545117	1.7	LHS	Wigan	Ponds & swamp
Wetland off Orchard Lane	SD661014	5.8	LHS	Wigan	Swamp, ponds, woodland & birds
Whelley Loop	SD580090	5.9	LHS	Wigan	Woodland
White Bridge Wood	SD577105	4.5	LHS	Wigan	Woodland
Wigsey Lane Meadows	SJ695889	5.5	LHS	Trafford	Grassland & birds

Table 1.1. Protected sites in Great Manchester Wetlands NIA at April 2018, showing site designations and features mentioned in the designation. Green highlight indicates sites that are predominantly semi-natural, orange highlight indicates predominantly ex-industrial sites. SAC (Special Area of Conservation); LNR (Local Nature Reserve); LHS (Local Heritage Site); LWT (Lancashire Wildlife Trust).

Site Name	Grid Reference	Area Ha	Site Grade	District	Features
Windy Bank Wood	SJ680971	6.9	LHS	Wigan	Woodland
Winick Old Quay	SJ592916	7.5	LHS	Warrington	Grassland & scrub
Winstanley Hall Woods	SD544033	4.9	LHS	Wigan	Woodland & plantation woodland
Woodland North Moss Fm	SJ716964	9.6	LHS	Salford	Woodland
Woodshaw Colliery	SD613070	17.8	LHS	Wigan	Plantation woodland
Worsley Filter Beds	SD743001	4.2	LHS	Salford	Reedbed
Worsley Woods	SD753010	38.7	LHS	Salford	Woodland birds & ponds
Worthington Lakes	SD583110	21.3	LHS	Wigan	Woodland & birds

In addition to the specific site-based conservation work, there was a realisation that linkages had to be developed between sites to allow movement of biota across the intervening landscape. Thus farmland, small areas of woodland, restored landscapes and transport corridors, such as the Leeds Liverpool canal and disused railways, provide additional habitat corridors and potentially contribute to species mobility.

The various habitats may be viewed as biodiverse rich islands amongst a predominantly urban desert. It has been proposed that species richness depends on island size and isolation from source populations MacArthur and Wilson (1967). They developed an equilibrium model based on the concept that when there is an addition of the number of species on an island, the island's immigration rate of new species will decrease while the extinction rate of resident species will increase. MacArthur and Wilson thus assume that there will be an equilibrium point where the immigration rate equals the extinction rate. They further hypothesize that an increase in island size will lower extinction rates while a decrease in distance between the island and the source region will raise immigration thus larger islands will have more species

than smaller islands (assuming these islands are comparably isolated) and isolated islands will have fewer species than islands more proximal to source regions (assuming these islands are equally large). The role of the conservation manager in this landscape setting is to increase island size and reduce distance between islands.

The range of habitats (see Table 1.2 for range size measurements), as shown in Figure 1.3, contain a large number of species, including several which are nationally rare. Together, the area's habitats are recognised as being nationally important. A range of Section 41 Species (threatened or declining) occur, including: Willow Tit (*Poecile montanus* Conrad von Baldenstein, 1827), Lapwing (*Vanellus vanellus* Linnaeus, 1758), Grey Partridge (*Perdix perdix* Linnaeus, 1758), Tree Sparrow (*Passer montanus* Linnaeus, 1758) and Water Vole (*Arvicola amphibious* Linnaeus, 1758). Unusual plants include Dune Helleborine (*Epipactis dunensis* (T. & T.A. Stephenson) Godfery), Cyperus Sedge (*Carex pseudocyperus* L.) and Royal Fern (*Osmundo regalis* L.).

This thesis has developed from my time as site manager of these sites, a job I have undertaken since its acquisition by Wigan MBC and LWT in 1999. The main aim of my role is to protect and enhance the Greenheart area for conservation and public enjoyment and develop its importance for the species and habitats therein. This has led me to develop an academic interest in both the ecological processes occurring in the area and to how conservation success can be assessed. The areas of the thesis reflect my own broad areas of wildlife interest but are unified by the purpose of developing practical approaches to the management of post-industrial land to deliver conservation gains.

Table 1.2. Summary of total habitat measurement by type in the Great Manchester wetlands NIA, compared to the total NIA area.

Great Manchester Wetland	**46445 ha**
Woodland	**1941 ha**
Grassland	**365 ha**
Heathland	**7 ha**
Reedbed and fen	**523 ha**
Raise mire	**158 ha**
Open water	**430 ha**
Water courses	**41 km**

Management of such sites is challenging. The sites originally listed by Ratcliffe (1977) are long established, semi-natural habitats, such as woodland or heathland, with traditional methods of management to draw upon. While ex-industrial sites frequently incorporate habitats found elsewhere, for instance reedbeds, they do present novel problems such as how to maintain diversity in a system undergoing succession as a result of soil development (Shaw, 1992, 2009). Hence management may sometimes require a novel or innovative approach for which a sound scientific basis is often lacking (Sutherland *et al*., 2004). Some of this lack of knowledge is a result of synanthropic habitats being viewed as less glamorous than other natural or semi-natural environments and therefore less studied. It is also partly a product of the disconnection between conservation biologists and conservation practitioners which has limited the exchange of ideas between the two groups (e.g. Arlettaz *et al*., 2010; Braunisch *et al.*, 2012; Pullin *et al*., 2004, 2009). This in turn has led to reviews by academics aimed at synthesising findings for practitioners (e.g. Sutherland *et al*., 2004; Pullin & Knight 2009; Dicks *et al*., 2013), with some practitioners involved in establishing the research agenda (e.g. Sutherland *et al*., 2011). The approach taken here is that the conservation research agenda is both set and investigated by the practitioner. The aim being to utilise evidence-based approaches to conservation management in the area.

Conservation needs to incorporate varying scales. The focus of conservation was traditionally at a species level with a community, or habitat-based approach following as species' ecology became more fully understood. This in turn led to an appreciation of the need to maintain levels of genetic diversity within a species, such that there is sufficient genetic diversity that the taxa can respond to selection. Following the Convention on Biodiversity Strategic Plan 2011-2020, which in the UK (United Kingdom) led to the Lawton report (2010), the concept of landscape-based conservation has been afforded a much higher priority than previously. These different levels of conservation, in turn, are the focus of this thesis, from a landscape-based approach, through a community focus, species-based conservation and concluding with a consideration of the evolutionary potential of the area.

This also reflects the change in scope of the work in the area during the last eighteen years from single site-based conservation projects, such as the Wigan Flashes, to a more landscape-scale approach. This approach is taken in the first major chapter, whereby the various reedbed communities in the area are assessed as to whether they are functioning as a single unit based upon the dispersal distances and area required by reedbed specialists.

The second major chapter has a community ecology focus and investigates the success of a sixteen-year grassland creation project. Six sites were chosen to recreate the hay meadows that were likely to be common in the area prior to the Industrial Revolution. Different meadow management techniques have been applied over the period and regular monitoring of species allows the question to be asked as to how successful meadow creation can be on ex-industrial land and how they should be managed.

The third chapter utilises a species-based approach to conservation and assesses the habitat requirements of the Willow Tit (*P. montanus*) in the woodlands of the Wigan flashes. Willow

Tit is the fastest declining UK bird species (Amar, 2006), but the Wigan population remains stable. The majority of nesting pairs in Britain are found in areas of extensive brownfield land. This study investigates if there are habitat requirements that reflect this apparent bias towards ex-industrial land and what can we do to conserve this endemic subspecies within the peri-urban setting.

The fourth major chapter explores the evolutionary dynamics of such sites. Utilising the hybridisation that the marsh orchids (*Dactylorhiza* spp.) undergo where their ranges overlap, alongside the hypothesis that ex-industrial sites provide disturbed habitats that promote hybridisation, this chapter examines the extent of hybridisation between Southern and Northern Marsh orchids (*D. praetermissa* (Druce) Soó (1962) and *D. purpurella* (T. Stephenson & T.A. Stephenson) Soó (1962)) across a mixture of disturbed and less disturbed habitats.

A final chapter summarises the thesis and identifies areas of future work.

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Chapter 2: Reedbed conservation on a landscape scale

2.1. Introduction

Since the establishment of the first nature reserves in Britain, conservation has primarily been focused upon the individual reserve or components within it. Thus, conservation success is typically measured by the maintenance of a particular habitat or community or by the numbers of a particular species. However, the Lawton (2010) report identified a landscape-scale approach as the key to future conservation direction. From an ecological perspective, considering nature reserves as islands of biodiversity *sensu* MacArthur and Wilson (1967), landscape scale conservation is an attempt to reduce the distances between islands via corridors or stepping stones. This approach has been adopted as policy by NGOs (National Government Organisations) such as the RSPB (Royal Society for the Protection of Birds) with their Futurescapes Initiative and the Wildlife Trusts with their Living Landscapes project. At a government level, the change in outlook was manifest in the introduction of Nature Improvement Areas (NIAs) following the 2011 White Paper. This identified twelve areas where a landscape-scale approach was to be undertaken. Following selection of NIAs, which all received government funding to develop, a second tranche of areas were treated as NIAs by NE (Natural England) and local authorities but did not receive significant additional funding. One of these was the Great Manchester Wetlands NIA. This covers 40000ha and incorporates fen and bog habitats within north-west England and involves local authorities, government bodies and NGOs. It included the Wigan Flashes and other areas of the Wigan Greenheart.

Within the Great Manchester Wetlands NIA are a number of reedbeds and reed fens. These are areas with a water table permanently at or above a neutral to basic soil surface and dominated by *Phragmites australis* (Cav.) Trin. Ex Steud.. They incorporate virtually uniform stands of *P. australis* (Reedbed; NVC (National Vegetation Classification) community S4) and other more diverse communities (Reed fens; S25 *Phragmites australis – Eupatorium*

cannabinum L. and S26 *Phragmites australis – Urtica dioica* L. tall herb fen; Rodwell *et al.,* 1995). These are important reedbed habitats for plants and animals including many rare species as shown by the meta-analysis of Valkama *et al.* (2008). In the UK (United Kingdom) this is reflected in the designation as a BAP (Biodiversity Action Plan) priority habitat. They also provide ecosystem services such as hydrological control and climate change mitigation through carbon storage (Turner and Daily, 2008; Fisher *et al*., 2011). In addition, reeds have important industrial applications, most notably for use as thatching material, but also as fencing, energy source and paper pulp (Köbbing *et al*., 2013).

The Great Manchester wetlands reedbed total 172 ha (Table 2.1), spread across 36 sites. This equates to just under 2% of the freshwater reedbed in the UK is therefore a significant national reedbed resource. The objective of the NIA is that the various reedbeds will function as a single interconnected series of units. This objective has led to active management of the reedbed resource, although conservation management of some of these sites predated establishment of the NIA.

When Wigan Flashes SSSI (Site of Special Scientific Interest) and the surrounding area was first taken into conservation management in 1996, the extensive reedbed was the primary reason for the area being identified for such treatment. Given its rarity, abundant potential habitat and occasional sighting in the area, it was decided that European Bittern (*Botaurus stellaris* Linnaeus, 1758) should be identified as the main priority species. The bittern therefore acted as a flagship species with the primary aim being to offset the decline in breeding numbers both in the UK and the rest of Europe but also to enabled wider conservation works that would benefit a range of other reedbed-dependant species. In addition to bittern, four other birds of reedbeds and associated habitats were included as target species: Reed Warbler (*Acrocephalus scirpaceus* Hermann, 1804), Sedge Warbler (*Acrocephalus schoenobaenus* Linnaeus, 1758), Reed Bunting (*Emberiza schoeniclus* Linnaeus, 1758) and Water Rail (*Rallus aquaticus* Linnaeus, 1758). The success of the reedbed management at

Wigan Flashes SSSI was considered by Champion and Ashton (2010). However, this was an approach for a single site. This chapter is a development of that study and aims to measure the habitat suitability and the potential connectivity of the reedbeds within the Great Manchester Wetlands NIA. This latter question requires a landscape-scale approach.

There is no single accepted approach to assessing the extent of landscape-scale connectivity. Approaches adopt a structural or a functional approach (LaPoint *et al*, 2015). Structural connectivity utilizes physical features of the landscape (eg area cover of a particular habitat type or isolation distance) whilst functional connectivity addresses whether a landscape is permeable to a particular organism. A common functional connectivity technique is to use GIS (Geographic Information Systems) allied to mathematical approaches, usually graph theory (Bishop-Taylor *et al*., 2018), circuit theory (e.g. Mui *et al*., 2017) or structural equation modelling (e.g. Capmourteres and Anand, 2016). Genetic methods are also common (e.g. Castilho *et al*., 2011). However, these modelling and genetic approaches are typically single species studies, often of charismatic fauna (for example Hedgehogs (*Erinaceus europaeus* Linnaeus, 1758) (Braaker *et al*., 2017), Iberian Lynx (*Lynx pardinus* Temminck, 1827) (Ferreres *et al*., 2001) and Freshwater Turtle (*Chrysemys picta* Schneider, 1783) (Bowne *et al*., 2006). Unsurprisingly, a multi-species approach is less common. Studies incorporating invertebrates are also unusual, where they have been undertaken butterflies are the most common subjects (e.g. Speckled Wood (*Pararge aegeria* Linnaeus, 1758), Chardon *et al*., 2003). The method utilised in this study is to draw upon the existing scientific literature for a number of a reedbed specialists including invertebrates and from this to identify the likely extent of connectivity within the Great Manchester Wetlands NIA. A number of species have been identified as reedbed specialists (Champion and Ashton, 2010). In this chapter I take these reedbed specialists and survey the literature to identify dispersal distances and territory required for breeding success. Thus, two key areas of an organism's life cycle are considered. Using this information, it can then be assessed whether the existing reedbed matrix in the Great Manchester Wetlands is functioning as single unit for all species, for this study the

abiotic quality of the reedbeds was not assessed. If this is not the case the requirements for additional reedbed habitat in this area can be identified.

2. 2. Methods

2. 2. 1. Locations

A total of 36 Reedbeds or reed fen habitat are present in the Great Manchester Wetlands NIA. Their locations are shown in Figures 2.1 and 2.2 and are listed with grid references, area of habitat and distance to nearest other reed habitat in Table 2.1. This is a list compiled from Wigan Council's Habitat audit (2010), NE priority Habitats Inventory (online), GMEU's (Greater Manchester Ecology Unit) data set plus knowledge from Warrington MBC staff and local naturalists. It was all then ground-proofed by the author by visiting the sites and identifying presence of reed in uniform stands.

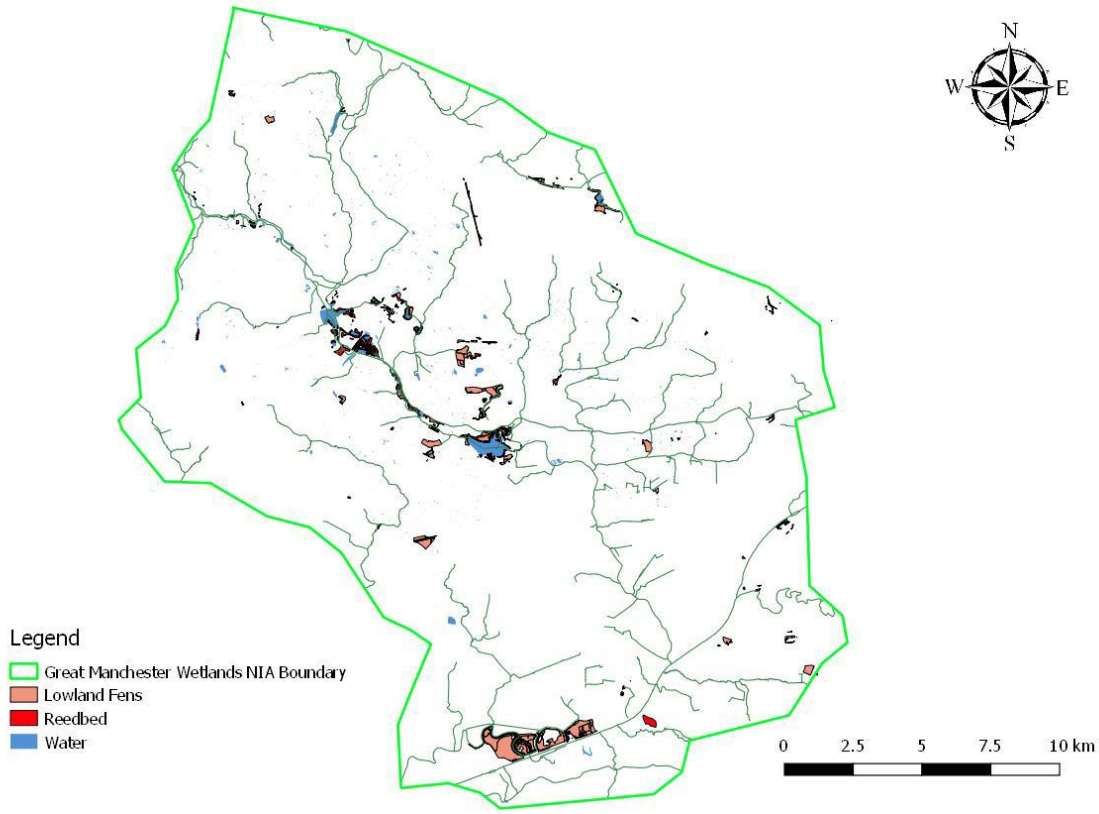

Figure 2.1. Distribution of Reedbeds, Reed fens and other aquatic habitats across the Great Manchester Wetlands NIA.

Table 2.1. Name, location, area and distance to nearest reedbed site for Reedbed and reed fen sites in the Great Manchester Wetlands NIA.

Location	Total Reedbed Area (ha)	Distance to nearest reedbed (m)	Grid Reference
Abram Flash	1.09	970	SD612002
Amberswood	1.95	1407	SD605040
Astley Green	0.94	4256	SJ704996
Astley Moss	3.80	956	SJ692975
Barlows Farm	0.23	411	SD627023
Barton Moss	0.06	4023	SD544007
Bickershaw	5.20	470	SD637009
Blackrod Railway	0.64	2300	SD632108
Botany Bay	0.18	1813	SD628063
Carrington	2.33	4448	SJ728930
Cutacre	0.11	499	SD707027
East Lancs Road	0.03	1200	SJ655977
Farnworth Centre	0.18	500	SD731056
Flixton	0.13	764	SJ735937
Golborne	0.08	799	SJ613985
Hic Bibi	0.40	4662	SD567126
Hindley Green	0.40	410	SD637027
Lightshaw	2.91	210	SJ615988
Low Hall	0.31	408	SD612033
M6 Marshes	0.10	4600	SD545117
Middlebrook Valley	0.40	1900	SD642092
Orrell Water Park	0.21	1753	SD532032
Pennington Flash	10.23	216	SJ635990
Douglas River Corridor	1.17	4605	SD551071
Rixton Clay Pits	0.90	4010	SJ685902

Table 2.1 (Continued). Name, location, area and distance to nearest reedbed site for Reedbed and reed fen sites in the Great Manchester Wetlands NIA.

Location	Total Reedbed Area (ha)	Distance to nearest reedbed (m)	Grid Reference
Rumworth	1.04	4396	SD677078
Standish	0.19	1796	SD561102
Three Sisters Country Park	0.10	1125	SD584010
Trafford	0.97	2800	SJ743961
Tyldesley	0.11	896	SD707815
Westleigh	0.08	578	SD648007
Windy Bank	0.14	1753	SJ680971
Woolston Eyes	63.93	4000	SJ647880
Worthington Reservoir	0.06	2804	SD584114
Marus Bridge Ochre Treatment Works	0.02	1888	SD565027
Wigan Flashes	71.70	210	SD581028

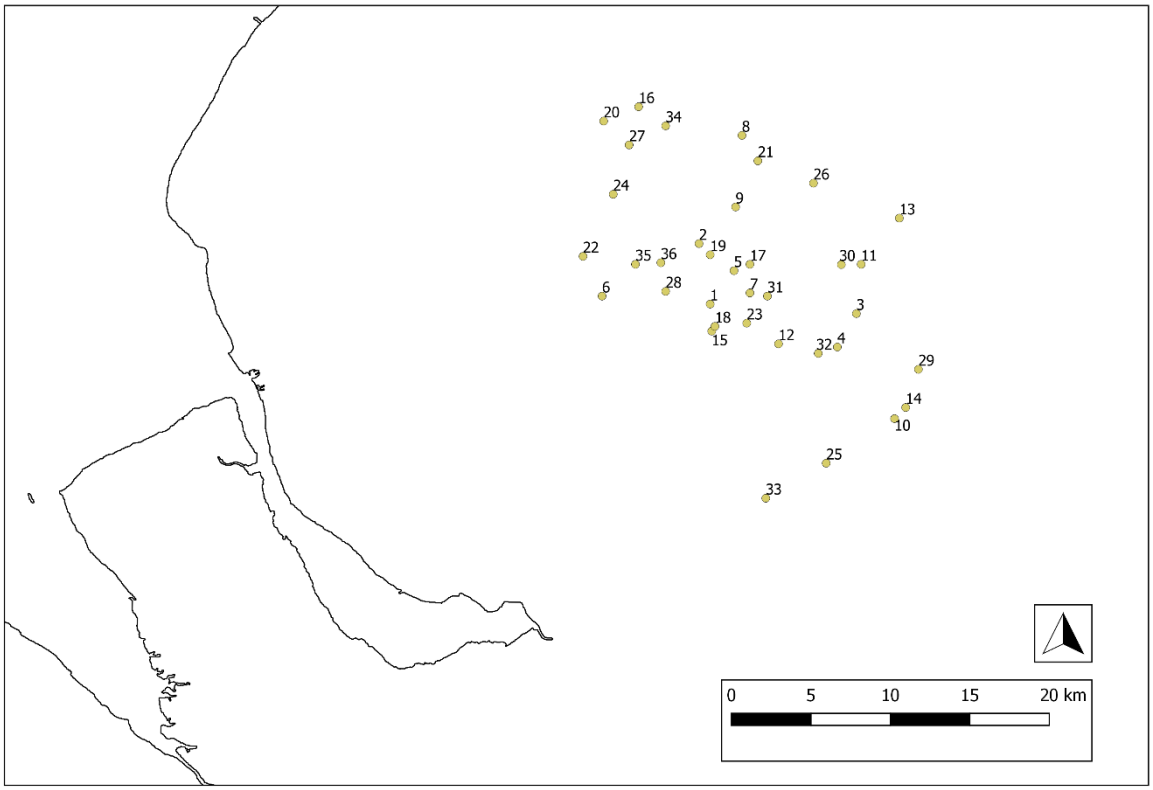

Figure 2.2. Reedbeds and reed fens across the Great Manchester Wetlands NIA. Key to site numbers: 1. Abram Flash; 2. Amberswood; 3. Astley Green; 4. Astley Moss; 5. Barlows Farm; 6. Barton Moss; 7. Bickershaw; 8. Blackrod Railway; 9. Botany Bay; 10. Carrington; 11. Cutacre; 12. East Lancs Road; 13. Farnworth Centre; 14. Flixton; 15. Golborne (school); 16. Hic Bibi; 17. Hindley Green-works; 18. Lightshaw; 19. Low Hall; 20. M6 Marshes; 21. Middlebrook Valley; 22. Orrell Water Park; 23. Pennington Flash; 24. Douglas River Corridor; 25. Rixton Clay Pits; 26. Rumworth; 27. Standish; 28. Three Sisters CP; 29. Trafford; 30. Tyldesley; 31. Westleigh; 32. Windy Bank; 33. Woolston Eyes; 34. Worthington Reservoir; 35. Marus Bridge Ochre Treatment Works; 36. Wigan Flashes.

2. 2. 2. Species, literature search and analysis

A list of UK reedbed specialist fauna was compiled by Champion and Ashton (2011), which incorporated both vertebrates and invertebrates. This list was modified by omitting all taxa that are not currently present in the north-west England, or not likely to be within the next decade given climate change predictions based upon UK Environmental Change Network data (Table 2.2). An online literature search was undertaken using Web of Science in February and March 2018 using the species name as search terms plus terms relevant to dispersal and habitat

area requirements. Where the species name returned no results, the genus was used as a search term. When genus returned no results the family was used or other closely related genera. This yielded a qualitative description of area required by the species and dispersal distance. A full list of search terms, results summaries and references are given in Table 2.2. This information was then placed in a matrix matching habitat requirements and potential dispersal distances of each species against the characteristics of each site (Table 2.3). For some categories there was no data available on the species, genus, related genera or families.

2. 3. Results

2.3.1. Habitats

There are 36 reedbed and reed fen sites within the Great Manchester NIA. They range in size from 0.02ha (Marus Bridge Ochre Treatment Works) to 71.70ha (Wigan Flashes). However, they are typically small, the median size is 0.35ha, with 15 of the sites being below 0.20ha. Apart from Wigan Flashes, the other two sites greater than 10ha are Woolston Eyes (63.93ha) in the south of the area and Pennington Flash (10.23ha) to the east of the Wigan group. These are located in a north-south range of 50km and an east-west range of 40km. They are not distributed evenly across the area. From a geographical perspective, they appear as a central cluster in the Wigan area. With all sites within a few kilometers of each other, and large expanse of reedbed close to Warrington and several outliers about 10-15km from the nearest cluster.

2.3.1. Species

The minimum habitat requirement and dispersal distance for each reedbed specialist is given in Table 2.2. The ability of each species to utilise the reedbeds within the Greater Manchester wetlands and potential to move to the next reedbed is given in Table 2.3.

Table 2.2 The Minimum Habitat requirement and dispersal distance for each reedbed specialist. Species currently recorded in the North West of England are denoted in green the first column, those with no previous records for the species in the NW are shown in orange. Those whose presence in the NW is unknown are in blue. Shading indicates species who are projected to expand into or from the NW due to climate change. Unless otherwise marked, all results were obtained from Web of Science on 22.02.18. Those not searched on that date are marked as follows: * 15/03/2018; **16/03/2018; ***19/03/2018; † 20/03/2018; †† 21/03/2018; ††† 22/03/2018.

Species	Area needed in habitat	Dispersal distance.	Method	Search terms (WoS)	Extra sources, citations, notes. Common resource: NBN Atlas.
Avifauna					
Bittern *Botaurus. Stellaris*	c20ha	*B. lentiginosus* - 2,300 km in less than 74 hrs.	Satellite tracking	**Botaurus stellaris*, dispersal, bittern, migration	Huschle G, Toepfer JE, Douglas DC (2013) Waterbirds 36:300–309
Marsh Harrier *Circus aeruginosus*	home ranges: non-breeding birds (1603 +/-SD 2128 ha), breeders (349 +/-SD 185 ha)	Sweden-western Africa, over 5800 km	Satellite tracking	***Circus aeruginosus*, migration	Home Range: Sternalski, A. et al. 2008. J. Zool. 274: 188–197. Dispersal distance:Y. Vardanis, et al, (2001) Biology Letters, 7 (4) pp. 502-505, 10.1098/rsbl.2010.1180
Teal *Anas crecca*	22.8-162ha	France-Asia/eastern Russia	Satellite tracking	****Anas crecca*, home range, migration	Home range: Legagneux et al., 2008.
Shoveler *Anas clypeata*	Similar to *Anas crecca*?	UK-France, Iberia, Mediterranean	Ringing	*Anas clypeata*, migration, home range	Dispersal: Kirby & Mitchell, 1993
Water Rail *Rallus aquaticus*	Conflicting/dependant on density -): Water Rail density (6.4–7.5 pairs/ha), avg size territories 320 m2; mean density equal to 0.75 pair/ha.	UK- Poland, Sweden	Ringing	*Rallus aquaticus*, home range, migration	(Jedlikowski et al. 2014) Flegg & Glue, 1973 Bengtson(1967
Reed Warbler *Acrocephalus scirpaceus*		Long distance: Europe - SE/W Africa	Ringing	†*Acrocephalus scirpaceus*, migration, home range	Kovacs et al., 2012
Sedge Warbler *Acrocephalus shcoenobaenus*		Long distance: Europe sub-Saharan Africa	Ringing	*Acrocephalus shcoenobaenus*, migration, home range	Kovacs et al., 2012
Grasshopper Warbler *Locustella naevia*		Long distance: Europe sub-Saharan Africa	Ringing	*Locustella naevia*, migration. No results for home range.	Bayly et al., 2011
Bearded Tit *Panurus biarmicus*	>10ha ?	Not a migrant	Mist netting	*Panurus biarmicus*, habitat	Poulin et al.,2002

Table 2.2 (continued) The Minimum Habitat requirement and dispersal distance for each reedbed specialist. Species currently recorded in the North West of England are denoted in green the first column, those with no previous records for the species in the NW are shown in orange. Those whose presence in the NW is unknown are in blue. Shading indicates species who are projected to expand into or from the NW due to climate change. Unless otherwise marked, all results were obtained from Web of Science on 22.02.18. Those not searched on that date are marked as follows: * 15/03/2018; **16/03/2018; ***19/03/2018; † 20/03/2018; †† 21/03/2018; ††† 22/03/2018.

Species	**Area needed in habitat**	***Dispersal distance*.**	**Method**	**Search terms (WoS)**	**Extra sources, citations, notes. Common resource: NBN Atlas.**
Reed Bunting *Emberiza schoeniclus*	not an important factor in occurrence of *E. s. witherbyi*, small and large reed-beds were equally suitable.	Scandinavia, Germany and France - SW Spain + Mediterranean (Villarán, 1999)		*Emberiza schoeniclus*, migration, habitat	Villarán, 1999; Vera et al., 2011 Vera et al., 2011
Non-avian vertebrate taxa					
Eel *Anguilla anguilla*	broad-headed individuals home range:0.296 -km2 +/- 0.04 S.E., narrow-headed individuals:0.143 km2 +/-0.02 S.E.,. However movement of 4+ km recorded, (estuarine environment)	5000km+, Aarestrup et al., 2009	Radio transmitter tags	*Anguilla anguilla*, home range, dispersal	Barry et al., 2015 Walker, 2014
Water vole *Arvicola amphibius*	Adult males: 2774.0 m2 which decreases after breeding, adult females 848.3 m2	water voles are capable to disperse several kilometres between different waterways and even watersheds, Aars et al., 2006	Radio collars,. Genetics study ?	*Arvicola amphibius*, home range, dispersal	Frafjord, 2016) Aars Et al., 2006
Water shrew *Neomys fodiens*	190 m^2 Robinson 2003, original paper unavailable	~500m ? Champneys, PhD thesis, 2012. Original paper) unavailable.	Original methods unavailable	*Neomys fodiens*, home range, range	Van Bemmel, A.C. & Voesenek, L.A.C.K. (1984). T (Pennant, 1771) i. Cantoni, D.
Harvest mouse *Micromys minutus*		160m ?	Unavailable - original paper is in French.	*Micromys minutus*, dispersal, home range, habitat	Favier, 2014
Otter *Lutra lutra*	Group ranges: 4.7 and 6.4 km, occupied by 2 and 4 females resp. Male ranges larger and overlap with multiple female group ranges	Up to 20km	Radio transmitters, use of coloured ear tags	††*Lutra lutra*, home range, dispersal	Kruuk, 1991
Grass snake *Natrix natrix*	adult males 1.85 ha, adult females 0.87 ha,	64.48 m Males, 41.93 m females,	Pit tags	*Natrix natrix*, home range	Reading 2012

Table 2.2 (continued) The Minimum Habitat requirement and dispersal distance for each reedbed specialist. Species currently recorded in the North West of England are denoted in green the first column, those with no previous records for the species in the NW are shown in orange. Those whose presence in the NW is unknown are in blue. Shading indicates species who are projected to expand into or from the NW due to climate change. Unless otherwise marked, all results were obtained from Web of Science on 22.02.18. Those not searched on that date are marked as follows: * 15/03/2018; **16/03/2018; ***19/03/2018; † 20/03/2018; †† 21/03/2018; ††† 22/03/2018.

Species	Area needed in habitat	*Dispersal distance*.	Method	Search terms (WoS)	Extra sources, citations, notes. Common resource: NBN Atlas.
Mollusca					
Vertigo moulinsiana	Little literature & much of what is available is inaccessible. Very small snail (~4mm).			Vertigo moulinsiana, habitat	Consistently cited: Drake, C. M. 2000. A review of the status, distribution and habitat requirements of Vertigo moulinsiana in England. Journal of Conchology 36: 63-79.
Oxyloma sarsi				*Oxyloma sarsi*	One paper, is inaccessible.
Mercuria confuse	One local site Norfolk Broads	Local dispersal		*Mercuria confuse*	0 results on WoS, 1 dataset available in NBN
Spiders and allies (Arachnida: Araneae and Pseudoscorpiones)					
Tetragnatha striata		Ballooning genus-dispersal over great distances. >1500km, Lee et al.,2014	Capture	*Tetragnatha*, habitat, range, dispersal	Duffey, 1998; Blandenier, 2009
Clubiona juvenis				Clubionidae, habitat, dispersal,	Duffey, 1998; Blandenier, 2010
Clubiona phragmites		Ballooning family - Blandenier, 2009	Suction trap	*Clubionidae*, habitat, dispersal,	Duffey, 1998; Blandenier, 2011
Araneus quadratus		Ballooning genus		*Araneus*, density, dispersal	Duffey, 1998; Blandenier, 2012
Donacochara speciosa		Linyphiidae - Long distance ballooning family		linyphiidae, range	Duffey, 1998; Blandenier, 2013
Entelecara omissa					Duffey, 1998; Blandenier, 2015
Gongylidiellum murcidum		Linyphiidae - ballooning family		*Gongylidiellum*, dispersal	Duffey, 1998; Blandenier, 2016
Pirata piscatorius		Lycosidae - unknown/short dispersal range - ground active hunters		Lycosidae, dispersal	Duffey, 1998; Blandenier, 2017
Pirata piraticus		Lycosidae - unknown/short dispersal range - ground active hunters		Lycosidae, dispersal	Duffey, 1998; Blandenier, 2018

Table 2.2 (continued) The Minimum Habitat requirement and dispersal distance for each reedbed specialist. Species currently recorded in the North West of England are denoted in green the first column, those with no previous records for the species in the NW are shown in orange. Those whose presence in the NW is unknown are in blue. Shading indicates species who are projected to expand into or from the NW due to climate change. Unless otherwise marked, all results were obtained from Web of Science on 22.02.18. Those not searched on that date are marked as follows: * 15/03/2018; **16/03/2018; ***19/03/2018; † 20/03/2018; †† 21/03/2018; ††† 22/03/2018.

Species	Area needed in habitat	*Dispersal distance*.	Method	Search terms (WoS)	Extra sources, citations, notes. Common resource: NBN Atlas.
Hypomma fulvum					Duffey, 1998; Blandenier, 2019
Pardosa amentata	Only spiderlings balloon - resident?	Lycosidae - Pardosa - ballooning genus,			Bonte 2007
Pachygnatha clercki		Pachygnatha - ballooning species in genus.		*Pachygnatha*, dispersal	Bell et al., 2005
Allomengea vidua		Linyphiidae - Ballooning family		No results for genus or species, linyphiidae used	
Bathyphantes approximatus		Linyphiidae - Ballooning family		*Bathyphantes*, dispersal	
Lophomma punctatum		Linyphiidae - Ballooning family		No results for genus/species, linyphiidae used	
Argyroneta aquatica		Cybaeidae - lives underwater, repleneshing air bubbles frequently. Dispersal range unknown		Cybaeidae, *Argyroneta aquatica, Argyroneta*, dispersal	
Floronia bucculenta		Linyphiidae - Ballooning family		*Floronia bucculenta, Floronia*, dispersal	
Hypomma bituberculatum		Linyphiidae - Ballooning family		*Hypomma bituberculatum, Hypomma*. No results	
Tallusia experta		Linyphiidae - Ballooning family		*Tallusia experta, Tallusia*. No results	
Pisaura mirabilis		Some species in Pisauridae family show ballooning in spiderlings,		*Pisaura mirabilis, Pisaura*, dispersal. No results regarding dispersal range.	Frost et al., 2013
Marpissa radiata					
Tetragnatha striata		Ballooning genus- dispersal over great distances. >1500km,			Lee et al.,2014
Stoneflies (Plecoptera)					
Nemoura dubitans		~60m from water channel,	Malaise	Plectoptera, dispersal	Petersen, 2004.

Table 2.2 (continued) The Minimum Habitat requirement and dispersal distance for each reedbed specialist. Species currently recorded in the North West of England are denoted in green the first column, those with no previous records for the species in the NW are shown in orange. Those whose presence in the NW is unknown are in blue. Shading indicates species who are projected to expand into or from the NW due to climate change. Unless otherwise marked, all results were obtained from Web of Science on 22.02.18. Those not searched on that date are marked as follows: * 15/03/2018; **16/03/2018; ***19/03/2018; † 20/03/2018; †† 21/03/2018; ††† 22/03/2018.

Species	Area needed in habitat	*Dispersal distance*.	Method	Search terms (WoS)	Extra sources, citations, notes. Common resource: NBN Atlas.
True bugs (Hemiptera). Group: Heteroptera					
Microvelia pygmaea					
Gerris lateralis		Movements >100m rare for other species in Gerris genus;	Following marked adults	*Gerris*, Dispersal	Fairburn, 1986
Leafhoppers, planthoppers, froghoppers, treehoppers (Auchenorrhyncha)					
Chloriona dorsata		Other species in family - migrate up to 240km;	Radar	Delphacidae, dispersal	Riley et a., 1991
Chloriona vasconica					
Pentastiridius leporinus					
Paralimnus phragmitis		Spp in genus travel 90-155 m,	Mark-recapture	*Paralimnus*, Dispersal; no results. Cicadellidae used	Blackmer, 2004
Flies (Diptera): Snail-killing flies, picture-winged flies, grass flies and allies (Acalyptrata)					
Cryptonevra consimilis					
Lipara similis					
Cryptonevra nigritarsis					
Elachiptera austriaca		Unknown		*Elachiptera*. Dispersal, chloropidae showed no relevant results	
Eribolus nanus					
Eribolus slesvicensis		Unknown		No results for genus or species. Chloropidae showed no relevant results	
Lipara rufitarsis		Unknown		*Lipara*. No relevant results when searched with 'dispersal'	
Parochthiphila spectabilis					
Anagnota bicolor		Unknown		Anthomyzidae, *Anagnota bicolor, Anagnota*. No relevant results	

Table 2.2 (continued) The Minimum Habitat requirement and dispersal distance for each reedbed specialist. Species currently recorded in the North West of England are denoted in green the first column, those with no previous records for the species in the NW are shown in orange. Those whose presence in the NW is unknown are in blue. Shading indicates species who are projected to expand into or from the NW due to climate change. Unless otherwise marked, all results were obtained from Web of Science on 22.02.18. Those not searched on that date are marked as follows: * 15/03/2018; **16/03/2018; ***19/03/2018; † 20/03/2018; †† 21/03/2018; ††† 22/03/2018.

Species	**Area needed in habitat**	***Dispersal distance*.**	**Method**	**Search terms (WoS)**	**Extra sources, citations, notes. Common resource: NBN Atlas.**
Hover flies (Syrphideae)					
Sphaerophoria loewi				Syrphidae, dispersal	
Craneflies (Tipulidae)					
Tipula marginella		Gene flow suggested between pops up to 200 km apart, wind assisted; Bearup, 2013	DNA analysis	*Tipula*, dispersal, distance	
Dicranomyia (I.) melleicauda complicata de Meijere		unknown		*Dicranomyia*, dispersal, flight	
Erioptera bivittata					
Dicranomyia danica		Unknown		*Dicranomyia*, dispersal, flight	
Thaumastoptera calceata		Flightless limoniidae		*Thaumastoptera calceata, Thaumastoptera*; no results. Limoniidae	
Molophilus pleuralis		Flightless limoniidae		*Molophilus pleuralis*, dispersal; no results.	
Blowflies, dung flies, flesh flies and allies (Calyptrata)					
Phaonia atriceps		1.6 km-2.4 km for other species in Muscidae family ;	Capture and Release	†††*Phaonia atriceps, Phaonia*	James 2017
Beetles (Coleoptera): Ground beetles (Carabidae)					
Demetrias imperialis					
Odacantha melanura					
Rove beetles and allies (Staphylinidae/Scydmaenidae/Silphidae)					
Manda mandibularis					
Stenus butrintensis		Unknown - numerous studies on staphs in agricultural/tropical environments, but not reedbeds. Suggested >100m	Mark and recapture	*Stenus butrintensis, Stenus*, dispersal, home range - no results. Used staphylinidae	da Silva,2015

Table 2.2 (continued) The Minimum Habitat requirement and dispersal distance for each reedbed specialist. Species currently recorded in the North West of England are denoted in green the first column, those with no previous records for the species in the NW are shown in orange. Those whose presence in the NW is unknown are in blue. Shading indicates species who are projected to expand into or from the NW due to climate change. Unless otherwise marked, all results were obtained from Web of Science on 22.02.18. Those not searched on that date are marked as follows: * 15/03/2018; **16/03/2018; ***19/03/2018; † 20/03/2018; †† 21/03/2018; ††† 22/03/2018.

Species	**Area needed in habitat**	***Dispersal distance*.**	**Method**	**Search terms (WoS)**	**Extra sources, citations, notes. Common resource: NBN Atlas.**
Stenus niveus		Unknown - numerous studies on staphs in agricultural/tropical environments, but not reedbeds. Suggested >100m	Mark and recapture	No results for *Stenus niveus*	da Silva,2015
Rugilus fragilis		Wide range of wet fen and dead vegetation	trapping and observation?	No records for *Rugilus fragilis* in NBN atlas or WoS. No relevant papers when *'Rugilus'* used as a search term.	
Cypha discoidea		<100 m ,	Mark and recapture	Staphylinidae used. No results for *'Cypha'*.	da Silva 2015
Dacrila fallax		<100 m	Mark and recapture	*Dacrila fallax, acrila*, Staphylinidae. No results	da Silva 2015
Aloconota longicollis		<100 m , da Silva 2015	Mark and recapture	*Aloconota longicollis , Aloconota*, staphylinidae	da Silva 2015
Stenus bifoveolatus		<100 m , da Silva 2015	Mark and recapture	*Stenus bifoveolatus, Stenus*, staphylinidae, dispersal	da Silva 2015
Stenus binotatus		<100 m , da Silva 2015	Mark and recapture	*Stenus binotatus, Stenus*, staphylinidae, dispersal	da Silva 2015
Stenus pubescens		<100 m , da Silva 2015	Mark and recapture	*Stenus pubescens, Stenus*, staphylinidae	da Silva 2015
Stenus solutus		<100 m , da Silva 2015	Mark and recapture	*Stenus solutus, Stenus,* staphylinidae. None relevant.	da Silva 2015
Paederus riparius		<100 m , da Silva 2015	Mark and recapture	*Paederus riparius*, staphylinidae. None relevant.	da Silva 2015

Table 2.2 (continued) The Minimum Habitat requirement and dispersal distance for each reedbed specialist. Species currently recorded in the North West of England are denoted in green the first column, those with no previous records for the species in the NW are shown in orange. Those whose presence in the NW is unknown are in blue. Shading indicates species who are projected to expand into or from the NW due to climate change. Unless otherwise marked, all results were obtained from Web of Science on 22.02.18. Those not searched on that date are marked as follows: * 15/03/2018; **16/03/2018; ***19/03/2018; † 20/03/2018; †† 21/03/2018; ††† 22/03/2018.

Species	**Area needed in habitat**	***Dispersal distance*.**	**Method**	**Search terms (WoS)**	**Extra sources, citations, notes. Common resource: NBN Atlas.**
Erichsonius cinerascens		<100 m , da Silva 2015	Mark and recapture	*Erichsonius cinerascens*, Staphylinidae, *Erichsonius*. No relevent results.	da Silva 2015
Tachyporus pallidus		<100 m , da Silva 2015	Mark and recapture	*Tachyporus pallidus*, staphylinidae, *Tachyporus*, dispersal. None relevant	da Silva 2015
Myllaena infuscate		<100 m , da Silva 2015	Mark and recapture	*Myllaena infuscate*, staphylinidae, *Myllaena*. No relevant results	da Silva 2015
Myllaena intermedia		<100 m , da Silva 2015	Mark and recapture	*Myllaena intermedia*, Staphylinidae, *Myllaena*. No relevant results	da Silva 2015
Myllaena minuta		<100 m , da Silva 2015	Mark and recapture	*Myllaena minuta*, Staphylinidae, *Myllaena*. No relevant results	da Silva 2015
Hygronoma dimidiata		<100 m , da Silva 2015	Mark and recapture	*Hygronoma dimidiata*, staphylinidae, *Hygronoma*. No results.	da Silva 2015
Alianta incana		<100 m , da Silva 2015	Mark and recapture	*Alianta incana, Alianta*, staphylinidae. No results.	da Silva 2015
Pachnida nigella		<100 m , da Silva 2015	Mark and recapture	*Pachnida nigella, Pachnida*, Staphylinidae. No results.	da Silva 2015
Ocyusa picina		<100 m , da Silva 2015	Mark and recapture	*Ocyusa picina, Ocyusa*, staphylinidae. No relevant results.	da Silva 2015

Table 2.2 (continued) The Minimum Habitat requirement and dispersal distance for each reedbed specialist. Species currently recorded in the North West of England are denoted in green the first column, those with no previous records for the species in the NW are shown in orange. Those whose presence in the NW is unknown are in blue. Shading indicates species who are projected to expand into or from the NW due to climate change. Unless otherwise marked, all results were obtained from Web of Science on 22.02.18. Those not searched on that date are marked as follows: * 15/03/2018; **16/03/2018; ***19/03/2018; † 20/03/2018; †† 21/03/2018; ††† 22/03/2018.

Species	**Area needed in habitat**	***Dispersal distance*.**	**Method**	**Search terms (WoS)**	**Extra sources, citations, notes. Common resource: NBN Atlas.**
Caddis flies (Trichoptera)					
?Grammotaulius nitidus					
?Limnephilus pati		7.3km per year when colonising, Gislasen et al., 2015 (Limnephilidae study)	Malaise		<60 from waterline, Petersen et al 2004
?Limnephilus tauricus		7.3km per year when colonising, Gislasen et al., 2015 (Limnephilidae study)	Malaise	*Limnephilus tauricus, Limnephilus*, dispersal	<60 from waterline, Petersen et al 2005
Anabolia brevipennis		7.3km per year when colonising, Gislasen et al., 2015 (Limnephilidae study)	Malaise	Limnephilidae	<60 from waterline, Petersen et al 2006
Agrypnia pagetana				*Agrypnia pagetana,* Phryganeidae, dispersal	
Limnephilus binotatus		7.3km per year when colonising, (Limnephilidae study) <60 from waterline	Malaise	Limnephilidae	Gislasen et al., 2015, Petersen et al 2007
Trichostegia minor		7.3km per year when colonising, (Limnephilidae study)	Malaise	Limnephilidae	Gislasen et al., 2015, Petersen et al 2007
Ants, bees and wasps (Hymenoptera: Aculeata)					
Anoplius claviventris				Anoplius, Pompilidae, dispersal, Anoplius claviventris. None relevant	

Table 2.2 (continued) The Minimum Habitat requirement and dispersal distance for each reedbed specialist. Species currently recorded in the North West of England are denoted in green the first column, those with no previous records for the species in the NW are shown in orange. Those whose presence in the NW is unknown are in blue. Shading indicates species who are projected to expand into or from the NW due to climate change. Unless otherwise marked, all results were obtained from Web of Science on 22.02.18. Those not searched on that date are marked as follows: * 15/03/2018; **16/03/2018; ***19/03/2018; † 20/03/2018; †† 21/03/2018; ††† 22/03/2018.

Species	Area needed in habitat	*Dispersal distance*.	Method	Search terms (WoS)	Extra sources, citations, notes. Common resource: NBN Atlas.
Odynerus simillimus					
Rhopalum gracile					
Passaloecus clypealis					
Hylaeus pectoralis					
Macropis europaea					
Moths (Lepidotera)					
Elachista maculicerusella		Mark-recapture studies of male indicated that, on average, males flew 67m in one night;	Capture from known start	Elachista maculicerusella, dispersal, Elachista, no results.	Hoddle et al., 2011
Chilo phragmitella				Overwintering moth. Not a migrant	
Donacaula forficella				Donacaula forficella,	
Orthinama vittata		Geometrid larvae may disperse over considerable distances by ballooning, e.g. Orkney Isles;		Orthinama vittata, Geometridae,	Leggett et al., 2011
Achanara dissoluta		>60 km in other Noctuidae species;	Trapping and observation	Noctuidae, dispersal	He et al., 2018
Mythimna obsolete		>60 km in other Noctuidae species;			He et al., 2018
Orthononama vittata		Geometrid larvae may disperse over considerable distances by ballooning, e.g. Orkney Isles;		Orthononama vittata, Orthononama, dispersal, Geometridae	Leggett et al., 2011

For the species whose ecology is well understood there are several that require large areas (>10m^2) and have good dispersal abilities (Otter (*Lutra lutra* Linnaeus, 1758), Bittern, Marsh Harrier (*Circus aeruginosus* Linnaeus, 1758), Teal (*Anas crecca* Linnaeus, 1758), Shoveler (*Anas clypeata* Linnaeus, 1758) and Bearded Tit (*Panurus biarmicus* Linnaeus, 1758). Another group have good dispersal distances but require only smaller habitat areas (Water Rail (*Rallus aquaticus* Linnaeus, 1758), Reed Bunting (*Emberiza schoeniclus* Linnaeus, 1758), Eel (Anguilla anguilla, Linnaeus, 1758), Water Vole (*Arvicola amphibious* Linnaeus, 1758), Water Shrew (*Neomys fodiens* Pennant, 1771), Grass Snake (*Natrix natrix* Linnaeus, 1758) and Harvest Mouse (*Micromys minutus* Pallas, 1771)). It is likely that the warblers fall into this category too, though minimum area has been hard to find from the literature. From general ecology, it can be considered that some groups of invertebrates have high dispersal ability but the minimum habitat areas are unknown (ballooning spiders and allies), while other groups have unknown habitat areas and unknown dispersal abilities (including Mollusca, flies, crane flies). The site matrix (Table 2.3) shows that for vertebrates, mobility between sites is possible, though the area of individual sites is frequently unable to support the species. For the invertebrates for which information is available, areas are typically large enough but dispersal distances too great for sedentary species.

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

Upper portion of cell signifies if the species can within its known range of dispersal access the nearest adjacent site. Lower portion of cell signifies whether the site is large enough to provide a suitable habitat. If "Yes" the portion of the cell is shaded green and if "No" the portion of the cell is shaded orange. Unknown information is shone by light blue shading. For aquatic animals, if “Yes”, the portion of the cell is shaded dark blue.

			Avifauna									
Area (Ha)	Distance (Meters)	Site/Species	*Botaurus stellaris*	*Circus aeruginosus*	*Anas crecca*	*Anas clypeata*	*Rallus aquaticus*	*Acrocephalus scirpaceus*	*Acrocephalus schoenobaenus*	*Locustella naevia*	*Panurus biarmicus*	*Emberiza schoeniclus*
0.11	896	Tyldsley										
0.4	4662	Hic Bibi										
0.1	4600	M6 Marshes										
0.06	2804	Worthington Reservoir										
0.19	1796	Blackrod Railway										
0.64	2300	Standish										
0.4	1900	Middlebrook Valley										
1.04	4396	Rumworth										
1.17	4605	Douglas River Corridor										
0.18	1813	Botany Bay										
0.18	500	Farnworth centre										
1.95	1407	Amberswood										
0.31	408	Low Hall										
0.21	1753	Orrell WaterPark										
0.02	1888	Marus Bridge OT Works 1										
71.7	210	Wigan Flashes										
0.4	410	Hindley Green										
0.11	499	Cutacre										

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Avifauna									
Area (Ha)	Distance (Meters)	Site/Species	*Botaurus stellaris*	*Circus aeruginosus*	*Anas crecca*	*Anas clypeata*	*Rallus aquaticus*	*Acrocephalus scirpaceus*	*Acrocephalus schoenobaenus*	*Locustella naevia*	*Panurus biarmicus*	*Emberiza schoeniclus*
0.23	411	Barlows Farm										
0.1	1125	Three Sisters CP										
5.2	470	Bickershaw										
0.08	578	Westleigh										
0.06	4023	Barton Moss										
1.09	970	Abram Flash										
0.94	4256	Astley Green										
10.23	216	Pennington Flash										
2.91	210	Lightshaw										
0.08	799	Golborne (School)										
0.03	1200	East Lancs Road										
3.8	956	Astley Moss										
0.14	1753	Windy Bank										
0.97	2800	Trafford										
0.13	764	Flixton										
2.33	4448	Carrington										
0.9	4010	Rixton Clay Pits										
63.93	4000	Woolston Eyes										

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Non-Avian Vertebrate Taxa					
Area (Ha)	Distance (Meters)	Site/Species	*Anguilla anguilla*	*Arvicola amphibius*	*Neomys fodiens*	*Micromys minutus*	*Lutra lutra*	*Natrix natrix*
0.11	896	Tyldsley						
0.4	4662	Hic Bibi						
0.1	4600	M6 Marshes						
0.06	2804	Worthington Reservoir						
0.19	1796	Blackrod Railway						
0.64	2300	Standish						
0.4	1900	Middlebrook Valley						
1.04	4396	Rumworth						
1.17	4605	Douglas River Corridor						
0.18	1813	Botany Bay						
0.18	500	Farnworth centre						
1.95	1407	Amberswood						
0.31	408	Low Hall						
0.21	1753	Orrell WaterPark						
0.02	1888	Marus Bridge OT Works 1						
71.7	210	Wigan Flashes						
0.4	410	Hindley Green						
0.11	499	Cutacre						

Note: Yellow cells in the case of Water Voles (*Arvicola amphibius*) signifies that males can live in that range size, but females cannot. For Grass snakes (*Natrix natrix*) yellow cells signify that the female can live in that range size, but the male cannot.

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Non-Avian Vertebrate Taxa					
Area (Ha)	Distance (Meters)	Site/Species	*Anguilla anguilla*	*Arvicola amphibius*	*Neomys fodiens*	*Micromys minutus*	*Lutra lutra*	*Natrix natrix*
0.23	411	Barlows Farm						
0.1	1125	Three Sisters CP						
5.2	470	Bickershaw						
0.08	578	Westleigh						
0.06	4023	Barton Moss						
1.09	970	Abram Flash						
0.94	4256	Astley Green						
10.23	216	Pennington Flash						
2.91	210	Lightshaw						
0.08	799	Golborne (School)						
0.03	1200	East Lancs Road						
3.8	956	Astley Moss						
0.14	1753	Windy Bank						
0.97	2800	Trafford						
0.13	764	Flixton						
2.33	4448	Carrington						
0.9	4010	Rixton Clay Pits						
63.93	4000	Woolston Eyes						

Note: Yellow cells in the case of Water Voles (*Arvicola amphibius*) signifies that males can live in that range size, but females cannot. For Grass snakes (*Natrix natrix*) yellow cells signify that the female can live in that range size, but the male cannot.

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Mollusca			Spiders and allies (Arachnida: Araneae and Pseudoscorpions)					Stone-flies
Area (Ha)	Distance (Meters)	Site/Species	*Vertigo moulinsiana*	*Oxyloma sarsi*	*Mercuria confuse*	*Various spiders & allies	*Clubiona juvenis*	*Entelecara omissa*	*Hypomma fulvum*	*Marpissa radiata*	*Nemoura dubitans*
0.11	896	Tyldsley									
0.4	4662	Hic Bibi									
0.1	4600	M6 Marshes									
0.06	2804	Worthington Reservoir									
0.19	1796	Blackrod Railway									
0.64	2300	Standish									
0.4	1900	Middlebrook Valley									
1.04	4396	Rumworth									
1.17	4605	Douglas River Corridor									
0.18	1813	Botany Bay									
0.18	500	Farnworth centre									
1.95	1407	Amberswood									
0.31	408	Low Hall									
0.21	1753	Orrell WaterPark									
0.02	1888	Marus Bridge OT Works 1									
71.7	210	Wigan Flashes									
0.4	410	Hindley Green									
0.11	499	Cutacre									

Note: Spiders and allies (Araneae and Pseudoscorpions) include: *Tetragnatha striata, Clubiona phragmites, Araneus quadratus, Donacochara speciosa, Larinioides cornutus, Gongylidiellum murcidum, Pirata piscatorius, Pirata piraticus, Pardosa amentata, Pachygnatha clercki, Allomengea vidua, Bathyphantes approximatus, Lophomma punctatum, Argyroneta aquatica, Floronia bucculenta, Hypomma bituberculatum, Tallusia experta* and *Pisaura mirabilis.*

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Mollusca			Spiders and allies (Arachnida: Araneae and Pseudoscorpions)					Stone-flies
Area (Ha)	Distance (Meters)	Site/Species	*Vertigo moulinsiana*	*Oxyloma sarsi*	*Mercuria confuse*	*Various spiders & allies	*Clubiona juvenis*	*Entelecara omissa*	*Hypomma fulvum*	*Marpissa radiata*	*Nemoura dubitans*
0.23	411	Barlows Farm									
0.1	1125	Three Sisters CP									
5.2	470	Bickershaw									
0.08	578	Westleigh									
0.06	4023	Barton Moss									
1.09	970	Abram Flash									
0.94	4256	Astley Green									
10.23	216	Pennington Flash									
2.91	210	Lightshaw									
0.08	799	Golborne (School)									
0.03	1200	East Lancs Road									
3.8	956	Astley Moss									
0.14	1753	Windy Bank									
0.97	2800	Trafford									
0.13	764	Flixton									
2.33	4448	Carrington									
0.9	4010	Rixton Clay Pits									
63.93	4000	Woolston Eyes									

Note: Spiders and allies (Araneae and Pseudoscorpions) include: *Tetragnatha striata, Clubiona phragmites, Araneus quadratus, Donacochara speciosa, Larinioides cornutus, Gongylidiellum murcidum, Pirata piscatorius, Pirata piraticus, Pardosa amentata, Pachygnatha clercki, Allomengea vidua, Bathyphantes approximatus, Lophomma punctatum, Argyroneta aquatica, Floronia bucculenta, Hypomma bituberculatum, Tallusia experta* and *Pisaura mirabilis.*

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Truebugs (diptera)		Auchenorrhyncha (Hoppers)				Diptera (flies)
Area (Ha)	Distance (Meters)	Site/Species	*Microvelia pygmaea*	*Gerris lateralis*	*Chloriona dorsata*	*Chloriona vasconica*	*Pentastiridius leporinus*	*Paralimnus phragmitis*	**Various flies (Diptera)*
0.11	896	Tyldsley							
0.4	4662	Hic Bibi							
0.1	4600	M6 Marshes							
0.06	2804	Worthington Reservoir							
0.19	1796	Blackrod Railway							
0.64	2300	Standish							
0.4	1900	Middlebrook Valley							
1.04	4396	Rumworth							
1.17	4605	Douglas River Corridor							
0.18	1813	Botany Bay							
0.18	500	Farnworth centre							
1.95	1407	Amberswood							
0.31	408	Low Hall							
0.21	1753	Orrell WaterPark							
0.02	1888	Marus Bridge OT Works 1							
71.7	210	Wigan Flashes							
0.4	410	Hindley Green							
0.11	499	Cutacre							

Note: Flies (Diptera) (snail killing flies, picture-winged flies, grass flies and allies (Acalyptrara)) include: *Cryptonevra consimilis, Lipara similis, Cryptonevra nigritarsis, Elachiptera austriaca, Eribolus nanus, Eribolus slesvicensis, Lipara rufitarsis, Parochthiphila spectabilis* and *Anagnota bicolor.*

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Truebugs (diptera)		Auchenorrhyncha (Hoppers)				Diptera (flies)
Area (Ha)	Distance (Meters)	Site/Species	*Microvelia pygmaea*	*Gerris lateralis*	*Chloriona dorsata*	*Chloriona vasconica*	*Pentastiridius leporinus*	*Paraliimnus phragmitis*	**Various flies (Diptera)*
0.23	411	Barlows Farm							
0.1	1125	Three Sisters CP							
5.2	470	Bickershaw							
0.08	578	Westleigh							
0.06	4023	Barton Moss							
1.09	970	Abram Flash							
0.94	4256	Astley Green							
10.23	216	Pennington Flash							
2.91	210	Lightshaw							
0.08	799	Golborne (School)							
0.03	1200	East Lancs Road							
3.8	956	Astley Moss							
0.14	1753	Windy Bank							
0.97	2800	Trafford							
0.13	764	Flixton							
2.33	4448	Carrington							
0.9	4010	Rixton Clay Pits							
63.93	4000	Woolston Eyes							

Note: Flies (Diptera) (snail killing flies, picture-winged flies, grass flies and allies (Acalyptrara)) include: *Cryptonevra consimilis, Lipara similis, Cryptonevra nigritarsis, Elachiptera austriaca, Eribolus nanus, Eribolus slesvicensis, Lipara rufitarsis, Parochthiphila spectabilis* and *Anagnota bicolor.*

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Rove beetles and allies (Staphylinidae/Scydmaenidae/Silphidae)					Hover-flies
Area (Ha)	Distance (Meters)	Site/Species	*Mando mandibularis*	*Stenus butrintensis*	*Stenus niveus*	*Rugilus fragilis*	*Various beetle species (17)	*Sphaerophoria loewi*
0.11	896	Tyldsley						
0.4	4662	Hic Bibi						
0.1	4600	M6 Marshes						
0.06	2804	Worthington Reservoir						
0.19	1796	Blackrod Railway						
0.64	2300	Standish						
0.4	1900	Middlebrook Valley						
1.04	4396	Rumworth						
1.17	4605	Douglas River Corridor						
0.18	1813	Botany Bay						
0.18	500	Farnworth centre						
1.95	1407	Amberswood						
0.31	408	Low Hall						
0.21	1753	Orrell WaterPark						
0.02	1888	Marus Bridge OT Works 1						
71.7	210	Wigan Flashes						
0.4	410	Hindley Green						
0.11	499	Cutacre						

Note: Beetle species (Staphylinidae/Scydmaenidae/Silphidae) include*: Cypha discoidea, Dacrila fallax, Aloconota longicollis, Stenus bifoveolatus, Stenus binotatus, Stenus pubescens, Stenus solutus, Paederus riparius, Erichsonius cinerascens, Tachyporus pallidus, Myllaena infuscate, Myllaena intermedia, Myllaena minuta, Hygronoma dimidiata, Alianta incana, Pachnida nigella* and *Ocyusa picina.*

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Rove beetles and allies (Staphylinidae/Scydmaenidae/Silphidae)					Hover-flies
Area (Ha)	Distance (Meters)	Site/Species	*Mando mandibularis*	*Stenus butrintensis*	*Stenus niveus*	*Rugilus fragilis*	*Various beetle species (17)	*Sphaerophoria loewi*
0.23	411	Barlows Farm						
0.1	1125	Three Sisters CP						
5.2	470	Bickershaw						
0.08	578	Westleigh						
0.06	4023	Barton Moss						
1.09	970	Abram Flash						
0.94	4256	Astley Green						
10.23	216	Pennington Flash						
2.91	210	Lightshaw						
0.08	799	Golborne (School)						
0.03	1200	East Lancs Road						
3.8	956	Astley Moss						
0.14	1753	Windy Bank						
0.97	2800	Trafford						
0.13	764	Flixton						
2.33	4448	Carrington						
0.9	4010	Rixton Clay Pits						
63.93	4000	Woolston Eyes						

Note: Beetle species (Staphylinidae/Scydmaenidae/Silphidae) include*: Cypha discoidea, Dacrila fallax, Aloconota longicollis, Stenus bifoveolatus, Stenus binotatus, Stenus pubescens, Stenus solutus, Paederus riparius, Erichsonius cinerascens, Tachyporus pallidus, Myllaena infuscate, Myllaena intermedia, Myllaena minuta, Hygronoma dimidiata, Alianta incana, Pachnida nigella* and *Ocyusa picina.*

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Craneflies						Caly-ptrata	Beetles (Coleoptera): Ground beetles	
Area (Ha)	Distance (Meters)	Site/Species	*Tipula marginella*	*Dicranomyia (I.) melleicauda de complicata Meijere*	*Eriopter a bivittata*	*Dicranomyia danica*	*Thaumastoptera calceata*	*Molophilus pleuralis*	*Phaonia atriceps*	*Demetrias imperialis*	*Odacantha melanura*
0.11	896	Tyldsley									
0.4	4662	Hic Bibi									
0.1	4600	M6 Marshes									
0.06	2804	Worthington Reservoir									
0.19	1796	Blackrod Railway									
0.64	2300	Standish									
0.4	1900	Middlebrook Valley									
1.04	4396	Rumworth									
1.17	4605	Douglas River Corridor									
0.18	1813	Botany Bay									
0.18	500	Farnworth centre									
1.95	1407	Amberswood									
0.31	408	Low Hall									
0.21	1753	Orrell WaterPark									
0.02	1888	Marus Bridge OT Works 1									
71.7	210	Wigan Flashes									
0.4	410	Hindley Green									
0.11	499	Cutacre									

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Craneflies						Caly-ptrata	Beetles (Coleoptera): Ground beetles	
Area (Ha)	Distance (Meters)	Site/Species	*Tipula marginella*	*Dicranomyia (L.) melleicauda de complicata Mejere*	*Eriopter a bivittata*	*Dicranomyia danica*	*Thaumastoptera calceata*	*Molophilus pleuralis*	*Phaonia atriceps*	*Demetrias imperialis*	*Odacantha melanura*
0.23	411	Barlows Farm									
0.1	1125	Three Sisters CP									
5.2	470	Bickershaw									
0.08	578	Westleigh									
0.06	4023	Barton Moss									
1.09	970	Abram Flash									
0.94	4256	Astley Green									
10.23	216	Pennington Flash									
2.91	210	Lightshaw									
0.08	799	Golborne (School)									
0.03	1200	East Lancs Road									
3.8	956	Astley Moss									
0.14	1753	Windy Bank									
0.97	2800	Trafford									
0.13	764	Flixton									
2.33	4448	Carrington									
0.9	4010	Rixton Clay Pits									
63.93	4000	Woolston Eyes									

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Caddis flies (Trichoptera)							Hymen-optera
Area (Ha)	Distance (Meters)	Site/Species	*?Grammotaulius nitidus*	*?Limnephilus pati*	*?Limnephilus tauricus*	*Anabolia brevipennis*	*Agrypnia pagetana*	*Limnephilus binotatus*	*Trichostegia minor*	*Various Hymenoptera*
0.11	896	Tyldsley								
0.4	4662	Hic Bibi								
0.1	4600	M6 Marshes								
0.06	2804	Worthington Reservoir								
0.19	1796	Blackrod Railway								
0.64	2300	Standish								
0.4	1900	Middlebrook Valley								
1.04	4396	Rumworth								
1.17	4605	Douglas River Corridor								
0.18	1813	Botany Bay								
0.18	500	Farnworth centre								
1.95	1407	Amberswood								
0.31	408	Low Hall								
0.21	1753	Orrell WaterPark								
0.02	1888	Marus Bridge OT Works 1								
71.7	210	Wigan Flashes								
0.4	410	Hindley Green								
0.11	499	Cutacre								

Note: Hymenoptera (Aculeata. ants, bees and wasps) include: *Anoplius claviventris, Odynerus similimus, Rhopalum gracile, Passaloecus clypealis, Hylaeus pectoralis* and *Macropis europeae.*

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Caddis flies (Trichoptera)							Hymen-optera
Area (Ha)	Distance (Meters)	Site/Species	*?Grammotaulius nitidus*	*?Limnephilus pati*	*?Limnephilus tauricus*	*Anabolia brevipennis*	*Agrypnia pagetana*	*Limnephilus binotatus*	*Trichostegia minor*	*Various Hymenoptera*
0.23	411	Barlows Farm								
0.1	1125	Three Sisters CP								
5.2	470	Bickershaw								
0.08	578	Westleigh								
0.06	4023	Barton Moss								
1.09	970	Abram Flash								
0.94	4256	Astley Green								
10.23	216	Pennington Flash								
2.91	210	Lightshaw								
0.08	799	Golborne (School)								
0.03	1200	East Lancs Road								
3.8	956	Astley Moss								
0.14	1753	Windy Bank								
0.97	2800	Trafford								
0.13	764	Flixton								
2.33	4448	Carrington								
0.9	4010	Rixton Clay Pits								
63.93	4000	Woolston Eyes								

Note: Hymenoptera (Aculeata. ants, bees and wasps) include: *Anoplius claviventris, Odynerus similimus, Rhopalum gracile, Passaloecus clypealis, Hylaeus pectoralis* and *Macropis europeae.*

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Moths (Lepidotera)					
Area (Ha)	Distance (Meters)	Site/Species	*Elachista maculicerusella*	*Chilo phragmitella*	*Donacaula forficella*	*Orthinama vittata*	*Achanara dissoluta*	*Mythimna obsoleta*
0.11	896	Tyldsley						
0.4	4662	Hic Bibi						
0.1	4600	M6 Marshes						
0.06	2804	Worthington Reservoir						
0.19	1796	Blackrod Railway						
0.64	2300	Standish						
0.4	1900	Middlebrook Valley						
1.04	4396	Rumworth						
1.17	4605	Douglas River Corridor						
0.18	1813	Botany Bay						
0.18	500	Farnworth centre						
1.95	1407	Amberswood						
0.31	408	Low Hall						
0.21	1753	Orrell WaterPark						
0.02	1888	Marus Bridge OT Works 1						
71.7	210	Wigan Flashes						
0.4	410	Hindley Green						
0.11	499	Cutacre						

Table 2.3 Site Table showing the theoretical mobility between sites of the various taxa that use reedbed habitat. Sites are arranged northernmost to southernmost.

			Moths (Lepidotera)					
Area (Ha)	Distance (Meters)	Site/Species	*Elachista maculicerusella*	*Chilo phragmitella*	*Donacaula forficella*	*Orthinama vittata*	*Achanara dissoluta*	*Mythimna obsoleta*
0.23	411	Barlows Farm						
0.1	1125	Three Sisters CP						
5.2	470	Bickershaw						
0.08	578	Westleigh						
0.06	4023	Barton Moss						
1.09	970	Abram Flash						
0.94	4256	Astley Green						
10.23	216	Pennington Flash						
2.91	210	Lightshaw						
0.08	799	Golborne (School)						
0.03	1200	East Lancs Road						
3.8	956	Astley Moss						
0.14	1753	Windy Bank						
0.97	2800	Trafford						
0.13	764	Flixton						
2.33	4448	Carrington						
0.9	4010	Rixton Clay Pits						
63.93	4000	Woolston Eyes						

2.4. Discussion

For a cluster of similar habitats to function as an integrated landscape unit, four things need to be in place; the habitats need to be of sufficient size to host individual species, the sites need to be sufficiently close that movement between them is possible, the routes between the sites need to allow movement and the habitats themselves need to be of a quality that the species can live and breed within them. For conservation to be successful at a landscape scale all of the above need to be in place for all species. This study has attempted to address the requirements of all reedbed specialists, found or likely to be found in all the north-west in terms of size of habitat and proximity to nearest similar site. As this is, in the main a GIS based study it has not considered the routes between sites or the specific habitat quality and hence suitability for the named species.

This study has revealed the paucity of information available on the vast majority of invertebrates. This is unsurprising, except for charismatic species of conservation interest (e.g. Marsh Fritillary (*Euphydryas aurinia* Rottemburg, 1775), Wahlberg *et al.,* 2002) little is known of invertebrate habitat requirements in any habitat. This makes assessing landscape-scale conservation success difficult. A simple but informative follow-on from this work would be to identify which invertebrates are present at each reedbed and use this to help ascertain habitat requirements.

Where dispersal distances are known and distance to the nearest site was within the dispersal ability of the species it is possible that such species utilise the reedbeds as metapopulations. This is typically the case with avifauna. This idea is explored more fully in the context of a different habitat in the Willow Tit chapter (Chapter 4). Utilising the distance to the nearest site may be viewed as simplistic, given that sites within two distinct clusters would all record short nearest neighbour distance with the two clusters functioning as two separate landscape units. However, using this simple measure does show that no site is more than 5km from the nearest

other site. Moreover, the geographic patterning of sites in the Greater Manchester wetlands shows no particularly isolated group of sites. It is however recognized that this study would benefit from a more sophisticated approach to dispersal routes and distances, possibly by combining the information with GIS data. For example, Brooker (2002) looked at the relative likelihood of movement between nearest neighbor patches as determined from a computer simulation of bird dispersal in Australian woodland patches. However, there is too little known for many of the invertebrates for this approach to be adopted across all taxa.

The mean distances between sites is 2km. It is presumed that airborne species can generally move these distances, however this may not be the case. Among butterflies, for example, there can be wide variation in dispersal abilities (Baguette *et al*., 2000) it is difficult to predict dispersal ability for an individual species, although wing size was a weak indicator (Sekar, 2012). An important management approach at the landscape scale may be to develop suitable corridors. While these exist within the area through riverine systems, railways, canals and motorways, it is unknown whether reedbed specialists utilize these corridors. While various measures exist for assessing the effectiveness of conservation corridors (Gregory and Beier, 2014), population connectivity via corridors in urban landscapes is poorly understood (LaPoint et al, 2016). Existing studies are heavily biased towards vertebrates (Zeller *et al*, 2012; LaPoint *et a*l, 2015). Moreover potential corridors don't necessarily provide the same ecological opportunities. For instance, roads and railways differ in a number of aspects that may influence dispersal such as width of corridor and regularity of disturbance ((Borda-de-Água *et al*, 2017; Barrientos *et a*l, 2019). Perceived corridors may actually act as barriers (Holderegger and Di Guilio, 2010) as in the case of Moor Frog (*Rana arvalis* Nilsson 1842) in the Netherlands (Arens *et al* 2007). Nevertheless roads have been shown to act as conduits for movement in earthworms (*Dendrobaena octaedra* Savigny 1826; Cameron *et al*, 2008), Roesel's Bush-cricket (*Metrioptera roeseli* Hagenbach 1822; Holzhauer *et al*, 2006) while green corridors have enabled gene flow by Roe Deer (*Capreolus capreolus* L.) in Switzerland (Burkharta *et al*, 2016), Eastern Tiger Salamanders (*Ambystoma tigrinum* Green 1825) in New York and

New Jersey. While white footed mice (*Peromyscus leucopus* Rafinesque 1818) have used the green of the canopy as corridors to move between the urban grey in New York (Munshi-South, 2012). The challenge in understanding corridor connectivity is to address the taxonomic bias such that invertebrates are more fully understood and to develop a multi taxon approach to corridor management.

While the river system in the area (Figure 2.1) suggests extensive connectivity, the suitability of this system for dispersal in a predominantly urban habitat is rarely studied. The heterogeneous ecotones alongside the water course can be considered as a habitat in its own right (Weins, 2002) and Dallimer *et al* (2012) suggest that the dynamics of urban riparian zones are no different from nonriparian zones. They have been shown to act as dispersal corridors for riparian plant species (Sitzia *et al* 2018; Murray *et al,* 2019) and would presumably act as conduits for invertebrate species

The generally small size of the reedbeds means that they are typically too small to function as individual habitats for the larger vertebrates. Whether the close proximity of small sites allows some species to transcend an individual habitat requirement is worthy of consideration. Although, MacArthur and Wilson (1967) suggested that large patches of habitat are more viable than several small due to edge effects Simberloff *et al*. (1981) has suggested that the importance of scale of the patches and their distance apart is much more to maintaining populations is more reliant on the ability to colonise the habitats among the given taxa.

While increasing habitat size and connectivity, it is worth recognising that the presence of a particular habitat does not guarantee that the habitat is suitable for its specialist species. For reedbeds management needs to be undertaken to ensure that there are systems in place to maintain the dynamic structure of the reedbed for a range of species. Conservation advice is available to site managers as manuals (e.g. Hawke and José 1996) where Bittern conservation is targeted, and Kirby (1992) provided advice on invertebrates within reedbeds. The targeting

of the various reedbed taxa and providing suitable quality management and physical structure has been investigated widely notably for birds (Poulin and Lefebvre, 2002; Self, 2005) with the avian taxa responses to management being varied so that it is difficult to manage a reedbed for the full range of species. Others have used a more systems-based approach (e.g. Poudevigne, 2002) looking to provide a broader range of reedbed habitats in a dynamic river restoration setting.

The approach of utilising the literature to ascertain ecological requirements is a novel one albeit a logical one. Despite the absence of basic ecological information for many invertebrate species, the proximity of the habitats suggests that these may function as a landscape unit for mobile species that dispersal via the air. Where possible extensions to existing habitats may increase the species likely to occupy any one area. At the same time management for habitat quality is required at individual sites. Movement via water bodies may also be possible for aquatic species. It would be useful to explore gene flow between habitats. For all species this could be undertaken using molecular markers, additionally ringing methods would provide similar information for avifauna.

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Chapter 3 - Hay cutting and *Rhinanthus minor* redirect meadow creation in a synanthropic nature reserve.

3.1. Abstract

Species-rich, semi-natural grasslands are a threatened habitat in both the UK and Europe. The use of seed mixtures to recreate these habitats has been investigated in various field trials, whilst the field-scale application of these techniques over a decade or more has been less studied.

This study investigated the development of grassland habitats over a twelve-year period on a restored colliery shale site in the northwest of England. The grassland was originally seeded in the late 1980's with a commercial meadow mix plus arable annuals but remained unmanaged until 2000, when an annual hay cutting regime was initiated. In 2004 the grass hemi-parasite *Rhinanthus minor* L. (Yellow Rattle) was introduced. Since this species reintroduction community composition of the six meadows plus a control non-intervention area has been regularly recorded and compared to the UK National Vegetation Community MG5 *Centaureo-Cynosuretum cristati* Br.-Bl. & Tx hay meadow community. Soil analysis has also been undertaken.

The grassland areas have developed vegetation communities, which are increasingly similar to each other and increasingly typical of meadow vegetation, despite some differences in soil metal ion composition. Plant species richness and diversity have increased. The results show that the use of traditional land management techniques adapted for the post-restoration environment can deliver important regional, national and international conservation gains.

3.2. Introduction

Semi-natural grasslands, rich in species, are an important component of Britain's natural heritage. They are classified in the National Vegetation Classification (NVC) according to species assemblages that form characteristic communities (Rodwell, 1992). Mesotrophic grasslands (MG) are those that lack species associated with very acid or base-rich soil; Of these MG5 *Centaureo-Cynosuretum cristati* Br.-Bl. & Tx is an important species-rich community that was the widespread lowland hay meadow in England and is unique to the UK (Rodwell, 1992). It is typical of lowland brown soils with a pH between 4.5 and 6.5 and is characterized by the species *Cynosurus cristatus* L. and *Centaurea nigra* L. (Rodwell, 1992). The community is rich in forbs and the grasses *Festuca rubra* L., *C. cristatus* and *Agrostis capillaris* L., which are the most frequent (McCrea, 2004).

Species-rich, semi-natural grasslands are an important but threatened habitat throughout Europe, and much of the former area has been lost since the 1950s. (Jongepierová *et al*., 2007). Such sites were largely replaced by arable crops, or leys, sown with a few highly productive, artificial fertilisers demanding, grass species or were lost due to a change from a mid-summer cutting for hay to a spring mow for silage (Eriksson et al. 2002; Strijker 2005). The result has been significant loss of species-rich grassland (Fuller 1987; Cousins et al. 2007).

Increasing the numbers of species-rich grasslands, and the connectivity between them, has been identified as a conservation priority (Cousins et al. 2007; Arponen et al. 2013; Deák et al. 2018). Previous studies of grassland restoration have focused on the re-creation of grassland habitats on former arable fields (Conrad & Tischew 2011; Lencová & Prach 2011; Prach et al. 2014; Boecker et al. 2015) abandoned grasslands

(Buisson et al. 2015; Galvánek & Lepš 2008; Ruprecht 2006) or formerly improved hay meadows (Sullivan *et al*, 2019). An additional approach is to create meadows on brownfield sites using seed mixtures and subsequent management. However this is currently unexplored in the literature. This study is an attempt to fill this gap with an assessment of the success over time of meadow creation on synanthropic sites in the Wigan Flashes area.

The Wigan Flashes is a 242-ha site owned by Wigan Council located 1 km to the south of the town centre in the Greater Manchester administrative area. The post-industrial landscape created by mining subsidence, was subsequently tipped with materials including colliery shale, pulverised fuel ash (PFA) and boiler ash and consists of a range of habitats, including grassland meadows. The area was restored in the 1980s and has been managed by the Lancashire Wildlife Trust since 1999. The meadows are part of a wider nature reserve area and are located 1 km to the south of Wigan Town Centre in Lancashire at the Wigan Flashes Local Nature Reserve, Grid reference SJ 571 981 (Figure 3.1).

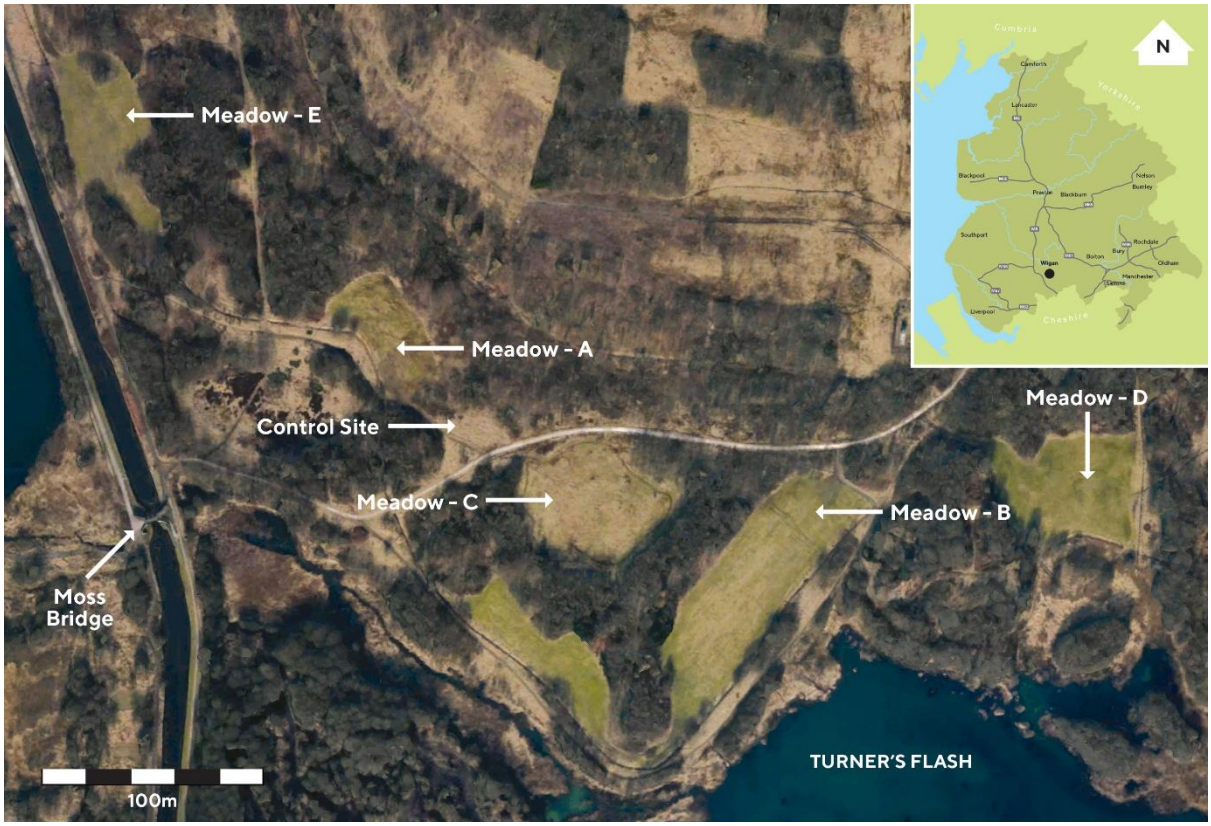

Figure 3.1 Locations of the five meadows created on synanthropic land at the Wigan Flashes LNR in 1990 and managed since 2000. (Insert shows area in NW England where sites are located).

In the late-1980s, the colliery shales were landscaped to form a low hill and covered in 10 cm of locally-sourced topsoil. The newly prepared ground was then limed to counteract the effects of the naturally occurring acidity from the colliery spoil, derived mainly from the breakdown of iron sulphide (FeS). The local authority then seeded the restored land surface with a perennial meadow mix including both grasses and forbs. The source of this seed mix has not been recorded, a product of the loss of paper based non-legal documentation during local government reorganisation in the 1990s (Wigan Council, pers. comm.). However, the composition of the seed mix is known (see Table 3.1). This restoration mix contains the most common grassland species found in local meadows and was available commercially. The mix was supplemented

with cornfield annuals which included *Papaver rhoeas* L. (Common Poppy), *Centaurea cyanus* L. (Cornflower), *Agrostemma githago* L. (Corncockle) and *Anthemis arvensis* L. (Corn Chamomile) The addition of these annuals was intended to help bind the soil and to give an attractive look to the newly restored land. When the land was restored in the 1980s it was considered that low soil fertility levels would limit the success of restoration efforts and so seeds of nitrifying leguminous species, including *Melilotus officinalis* (L.) Pall. (Ribbed Melilot), were also added. In addition, a superphosphate fertiliser was added when the original restoration took place, with the aim of promoting the establishment of the grassland on the coal spoil, although this may have been counterproductive. This approach to treatment and seed mix is typical of the time (Richardson, 1977). Subsequent work (eg Walker *et al.*, 2004) has shown that one of the most important abiotic constraints to grassland restoration is high residual soil fertility. It is now recognised that low levels of soil fertility are associated with high species co-existence on a wide range of semi-natural lowland grasslands (Janssens *et al*., 1998).

Although site managers at the time reported that the establishment was initially successful, the meadows were not managed for the next ten years, during which time there was a gradual decline in species richness and the area became dominated by coarser grasses such as *Arrhenatherum elatius* (L.) P. Beauv. ex J. Presl & C. Presl, *Trisetum flavescens* (L.) P. Beauv. and *Phalaris arundinacea* L. This is the common grassland type in the area on similar synanthropic where seeding had not been part of the management regime. This coarse grassland, typical of NVC OV27 (Rodwell, 2000),

The Wigan Flashes restored grasslands were not managed until 2000 when they were brought into management as meadows. This was achieved with the aid of agri-environment funding. This allowed for two key changes to the grassland management; hay cutting and the later introduction of *R. minor*. Although *R. minor* was in the original seed mixture there was no evidence of this in the meadows by 1999; it is considered that *R. minor* failed to grow into mature plants since there were no suitable host plants available in the first year.

The initial ten-year agri-environment grant allowed the establishment of a commercial hay cutting regime and this this was followed by another similar length agreement enabling the continuation of the grassland management. The cutting has been organised in partnership with a local farmer. The hay crop is cut between the last week of August and the middle of September each year. The timing of the cut was selected as this was the period when the key hay meadow species, *Centaurea nigra,* had set seed and the majority of the plants had seed heads ripe enough to drop seed during the hay tedding process.

After four years of the cutting regime, the decision was taken to introduce *R. minor*. This species is hemi-parasitic and it is often used as a conservation tool to reduce sward productivity because competitive, bulky grasses are known as host plants for the species (Bullock and Pywell, 2005). Seed was collected from a local site 10 km to the east, where a similar synanthropic grassland was found and similar ecotypes of *R. minor* recognised. The seed was sown by hand into the existing grasslands, the

ground was then scarified by hand to increase the seed germination (Westbury *et al*., 2006).

Grassland creation aims to produce a plant community that is representative of the target grassland type (Conrad & Tischew 2011; Waldén et al. 2017). However, there have been no evaluations of the success of grassland creation in synanthropic sites over time. Understanding temporal changes are important given the differential rate of establishment of plant species (von Gillhaussen et al. 2014; Engst et al. 2017). The system available to study at Wigan, created over 30 years ago, managed as hay meadows since 2000, with *R. minor* introduced in 2000, alongside regular monitoring and a control area presents a unique opportunity to study this process.

The success of grassland creation can be measured by comparisons with a reference or donor site, the proportion of target species present at a point in time, or the similarity between the new grasslands and a particular vegetation classification, typically the British National Vegetation Classification (NVC) (Rodwell 1992; Walker et al. 2004; Conrad & Tischew 2011; Kirkham et al. 2013). In the absence of a donor site or comparable local grassland this study used the NVC as reference, specifically the formerly widespread lowland hay meadow community MG5 *Centaureo-Cynosuretum cristati* Br.-Bl. & Tx (Rodwell, 1992). Thus, the study addresses how close the created meadows are to the target community and how this has changed over time.

Table 3.1 Composition by weight of the original commercial meadow seed mix. Note that unknown amounts of *Papaver rhoeas* L. (Common Poppy), *Centaurea cyanus* L. (Cornflower)*, Agrostemma githago* L. (Corncockle) and *Anthemis arvensis* L. (Corn Chamomile) and *Melilotus officinalis* (L.) Pall. (Ribbed Melilot) were added to this mix.

Scientific name	Common name	Percentage
Festuca rubra L.	Red Fescue	39.00%
Cynosurus cristatus L.	Crested Dog's-tail	34.50%
Trisetum flavescens (L.) P. Beauv.	Yellow Oat Grass	5.00%
Filipendula ulmaria (L.) Maxim.	Meadowsweet	3.10%
Centaurea nigra L.	Common Knapweed	3.90%
Plantago lanceolata L.	Ribwort Plantain	3.30%
Ranunculus bulbous L.	Bulbous Buttercup	2.00%
Ranunculus acris L.	Meadow Buttercup	1.60%
Rhinanthus minor L.	Yellow Rattle	1.60%
Agrostis capillaris L.	Common Bent	1.50%
Galium verum L.	Lady's Bedstraw	0.80%
Leontodon hispidus L.	Rough Hawkbit	0.80%
Lotus corniculatus L.	Bird's-foot Trefoil	0.80%
Agrimonia eupatoria L.	Agrimony	0.40%
Sanguisorba minor Scop.	Salad Burnet	0.40%
Prunella vulgaris L.	Self-heal	0.30%
Leucanthemum vulgare Lam.	Oxeye Daisy	0.20%
Achillea millefolium L.	Yarrow	0.10%

3.3. Methods

3.3.1 Vegetation sampling

The meadows were sampled using a modified NVC method (Rodwell, 1992). Five random quadrats of 2m x 2m per field were surveyed within the area of 'typical vegetation' in each meadow, thus avoiding flushes and damp spots. The first survey was undertaken prior to the first hay cut in 2000. Unfortunately no formal baseline records on meadow species composition exist until this point this time. Sampling was then repeated in 2004, prior to the introduction of *R. minor,* with further surveys in 2009, 2010 and 2012. No attempt was made to fix the quadrat locations between surveys. The percentage cover for each plant species was estimated and Domin scores were recorded for each quadrat. The sample was taken in June prior to hay cutting of any of the sites.

The results of the hay cutting regime are compared with a control plot adjacent to the meadows which had been part of the original restoration seeding but where hay cutting and seeding with *R. minor* was not implemented. In the control field the same survey method was used. However, for the sampling years 2000-2010 inclusive, the records for the control site were amalgamated so total species numbers by site are available whilst individual quadrat data are available for 2011 only. All vascular plants were identified, nomenclature according to Stace (2010).

3.3.3 Soil analysis

Soil analysis of the meadows was undertaken as part of an EHU Geography BSc project by Gilks (2012), supervised by Geography staff and myself. In 2011 soil was sampled randomly from five areas within each site, the four corners and the central area. For the control site only three sites were sampled, the NE and SW corners and the centre. Three samples of approximately 35g were taken from each area and bulked as per standard soil sampling methods. This yielded approximately 100g of soil. This was undertaken at three depths at each sample site (0-3cm, 3.1-9cm and 9.1-15cm). Before further analysis the soil was air dried until no more weight loss occurs. Large stones were removed and the soil passed through a 2mm sieve.

From these samples pH was determined using a pH electrode after adding approx 20g soil to 50ml of 1M KCl solution and stirring for two minutes, then leaving to settle for 15mins. This gives a solid liquid ratio of 1:2.5. The pH meter reading is taken when the reading is stable. Stability being a change of not more than 0.2pH units per 5 seconds (or 0.1pH unit per 30 seconds).

Soil organic content is determined using gravimetric methods using approximately 10 grams of soil in a muffle furnace at 450^{o}C for four hours.

Analysis for Nitrate and Orthophosphate content was undertaken using the Merck Reflectoquant Nitrate Test, (Cat.No. 1.16971.0001) and Merck Reflectoquant Phosphate Test, (Cat.No. 1.16978.0001) respectively. These methods both involve simple chemical preparation followed by insertion of a test strip into the preparation and then into a reflectometer. Nitrate ions are reduced to nitrite ions by a reducing agent. In the presence of an acidic buffer, these nitrite ions react with an aromatic

amine to form a diazonium salt, which in turn reacts with N-(1-naphthyl)-ethylenediamine to form a red-violet azo dye that is determined reflectometrically. Phosphate analysis utilises a similar approach using the phosphomolybdenum blue method.

Metal ion content (Ca, Mg, K, Cu, Zn, Pb) was determined using an AA spectrophotometer. This incorporated plant essential nutrients and potential contaminants from known previous land use. For further details of the method see Gilks (2012)

3.3.4 Data analysis

Non-metric multi-dimensional scaling (NMDS) using the metaMDS function in the vegan package (Oksanen *et al.,* 2016) was used to explore differences in community composition between the meadows in the different sampling years. Bray-Curtis distances were used in the analysis. NMDS is a valuable technique for investigating patterns in multivariate data, and is especially useful in community ecology datasets which have large numbers of zeros (McCune *et al*., 2002) Two ordinations were performed, one using Hellinger transformed percentage cover data (Legendre and Gallagher, 2001) and the other using frequency data. Domin scores were converted to percentage cover values prior to Hellinger transformation by the Domin 2.6 method (Currall, 1987). A conversion from Domin cover values to percentage cover provides linear data on which statistical operations such as the calculation of means are more straightforward, and the use of the Currall Domin 2.6 method has been shown to provide a more accurate reflection of percentage cover values than taking a mean of the range of each Domin score (Currall, 1987). The Hellinger transformation reduces

the effect of very abundant species which can mask the contribution of less common species in a large dataset. In the frequency data ordination, data for a typical MG5 meadow from the frequency table in the NVC surveys were included in the analysis (Rodwell, 1992).

In order to analyse whether the meadows were becoming more similar to the target vegetation type, the frequency data were entered into the Modular Analysis of Vegetation Information System MAVIS (Smart *et al*., 2016). The survey data are compared with the most likely match to a particular NVC community and a percentage similarity to specific NVC habitats is generated. The habitats were also checked against documentary sources using Rodwell (1992, 2000).

The change in the meadow flora over time was analysed by plotting the total species recorded for each meadow and for the control plot over each of the sampling years. Mean Shannon diversity indices for each meadow were calculated using the percentage cover data. The diversity indices were plotted by sampling year for all species, grasses and grass-like species, and for forbs. The change in MG5 species (listed in Rodwell, 1992) and non MG5 species was also plotted by sampling year, and the change in percentage cover and frequency of *R. minor* was calculated. Data analysis was carried out in R (R Core Team, 2017).

Comparison of meadow soil composition was undertaken with PCA following standardisation of results to give equal weighting to all variables.

3.4 Results

Figures 3.2 and 3.3 show soil analysis results.

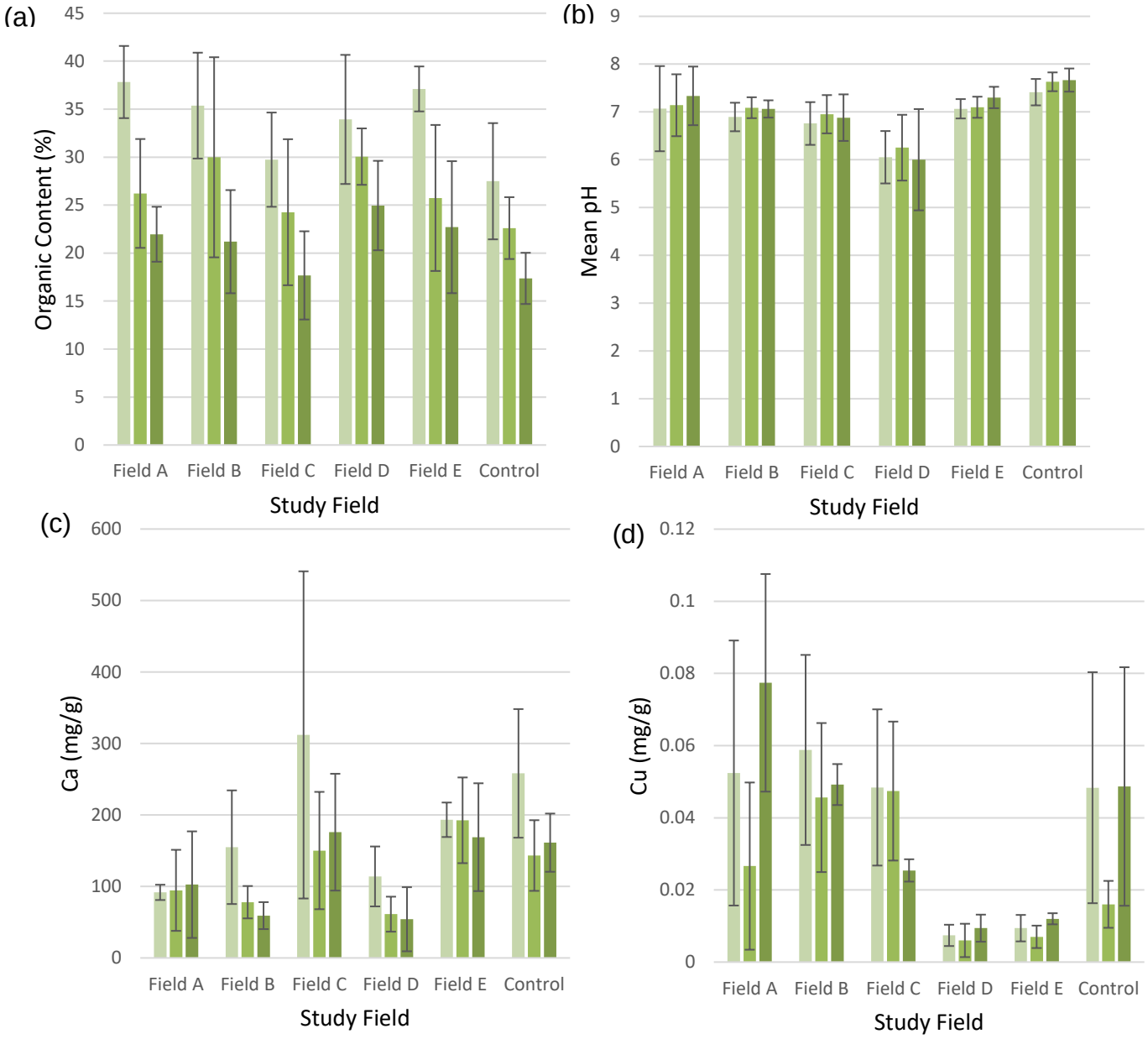

Figure 3.2. Bar graphs showing (a) mean percentage soil organic content, (b) mean pH, (c) mean calcium content, (d) mean copper content of each study field at varying depths. Error bars show standard deviation. Soil depth (cm): 0 - 30 31 - 90 91+

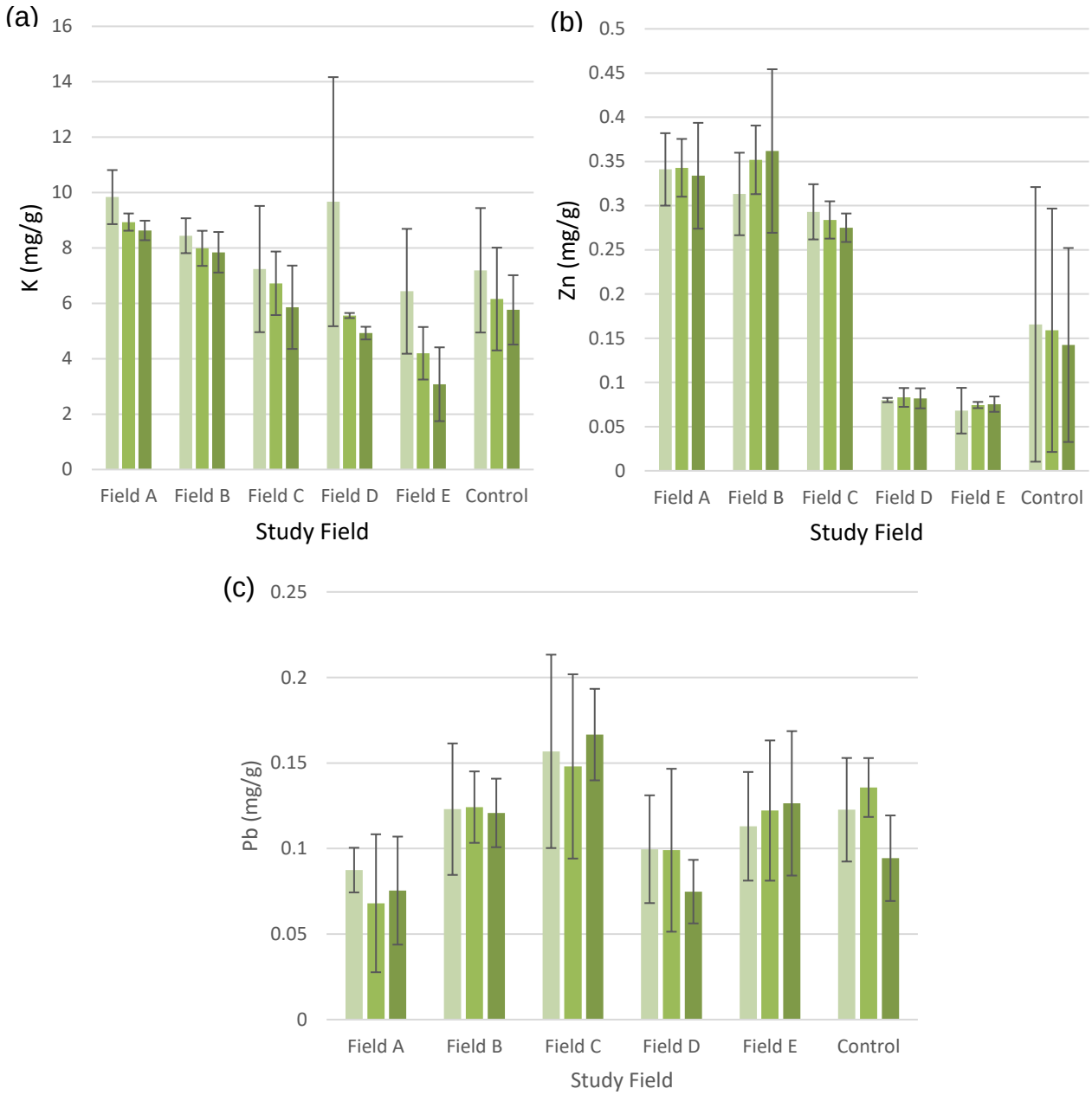

Figure 3.3. Bar graphs showing mean (a) mean Potassium content, (b) mean Zinc content and (c) mean Lead content of soil in all fields studied and the control. Error bars show standard deviation. Soil depth (mm): 0 - 30 31 - 90 91+

Figure 3.2. shows organic content declines with depth. pH typically increases with depth (except in Field D), Calcium is variable declining in fields B, C and D but increasing in A, E and Control. Magnesium declines with depth, Potasium (Figure 3.3)

is more or less constant with depth as are Zinc and Lead (Figure 3.3). Copper shows no trend through the depths having meadows were the top layer is the highest level (Field C), the middle layer has the highest level (Fields D, E and Control) and another with the lowest level having the highest copper content (Fields A and B). All soils had very low Nitrate and Phosphate levels. Nitrate levels were all below 5 - mg/l NO_3^- and Phosphate levels were all below 5 mg/l PO_4^{3-}.

There is notable varaition between sites in organic content, pH, Magenesium, Copper and Zinc content (Zinc content shown in Figure 3.3). Variation between sites in Potassium, Lead, Phosphorus and Nitrate levels were absent or small.

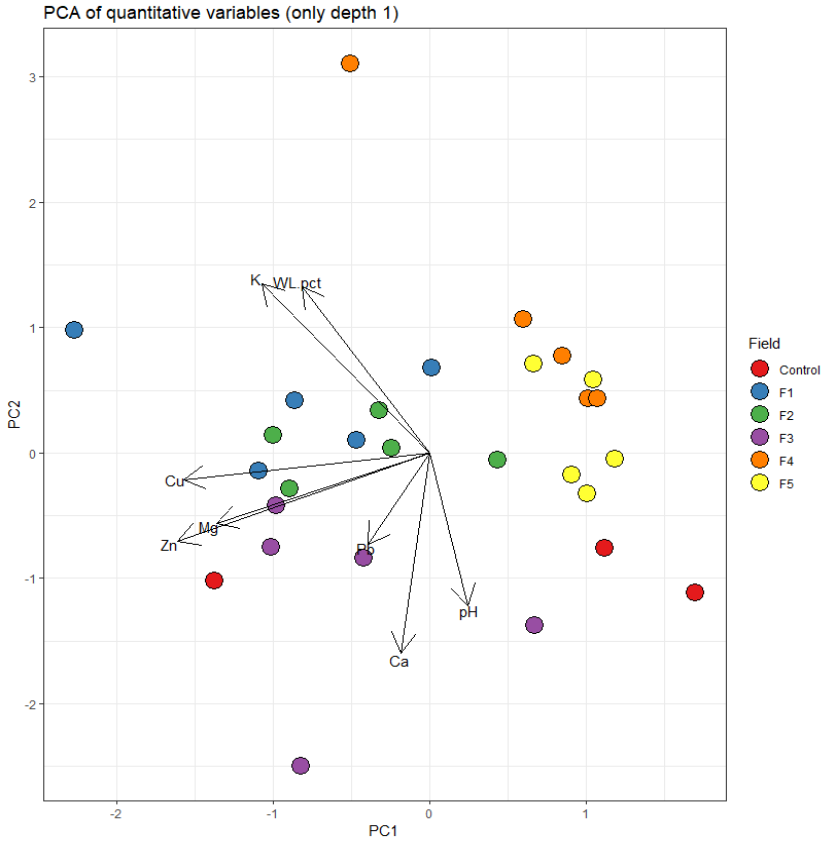

Figure 3.4. PCA of soil sample composition based upon metal ion content, pH and organics content in top 30 cm of soil.

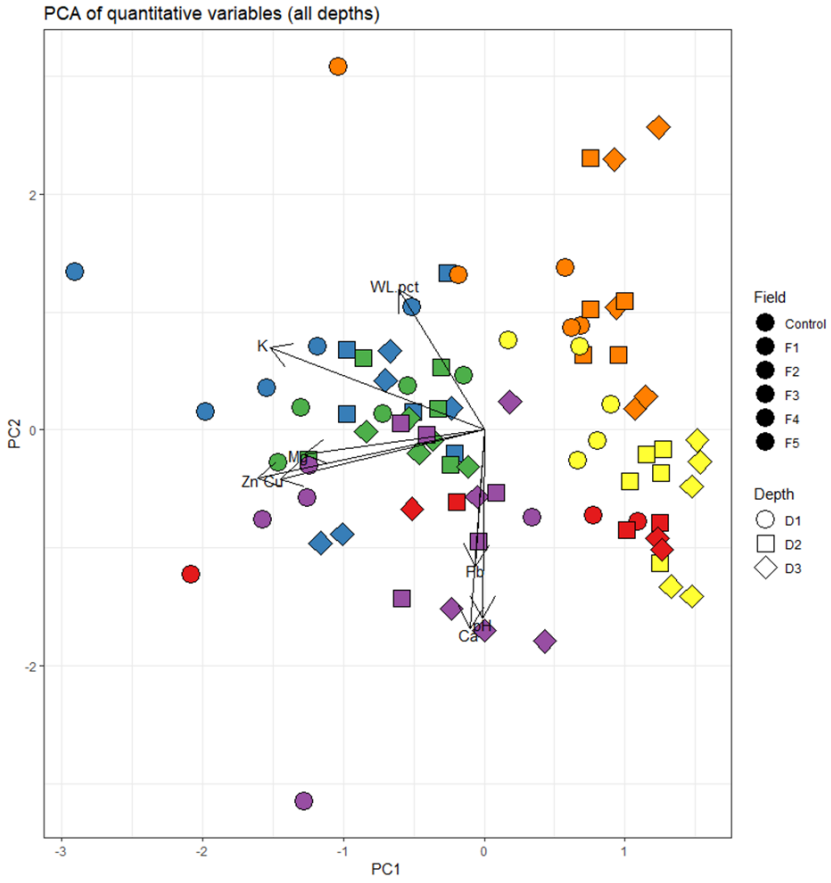

Figure 3.5. PCA of soil sample composition based upon metal ion content, pH and organics content utilising all three soil depths.

The PCA plots (Fig 3.4 and 3.5) show separation of meadows based upon combined soil characteristics. Considering only the shallowest soils, fields A, B and C are separated from the Control and fields D and E along PCA1 with the exception of two samples This axis is composed of Zinc, Magnesium and Copper content. A similar pattern is observed when all depths are considered. The PCA 1 axis separates fields A, B and C from Fields D, E and the Control plot with the exception of six outliers from fields D, E and Control, four of which are located within or close to the cluster representing fields A, B and C. The other two samples, one from the control and one from field D are outliers. This separation is due to the influence of levels of Zinc, Magensium and Copper. Within the right hand section of the plot field D and

the Control are separated along PCA 2. This is based upon higher organic content in Field D and higher Calcium, Lead and pH in the Control.

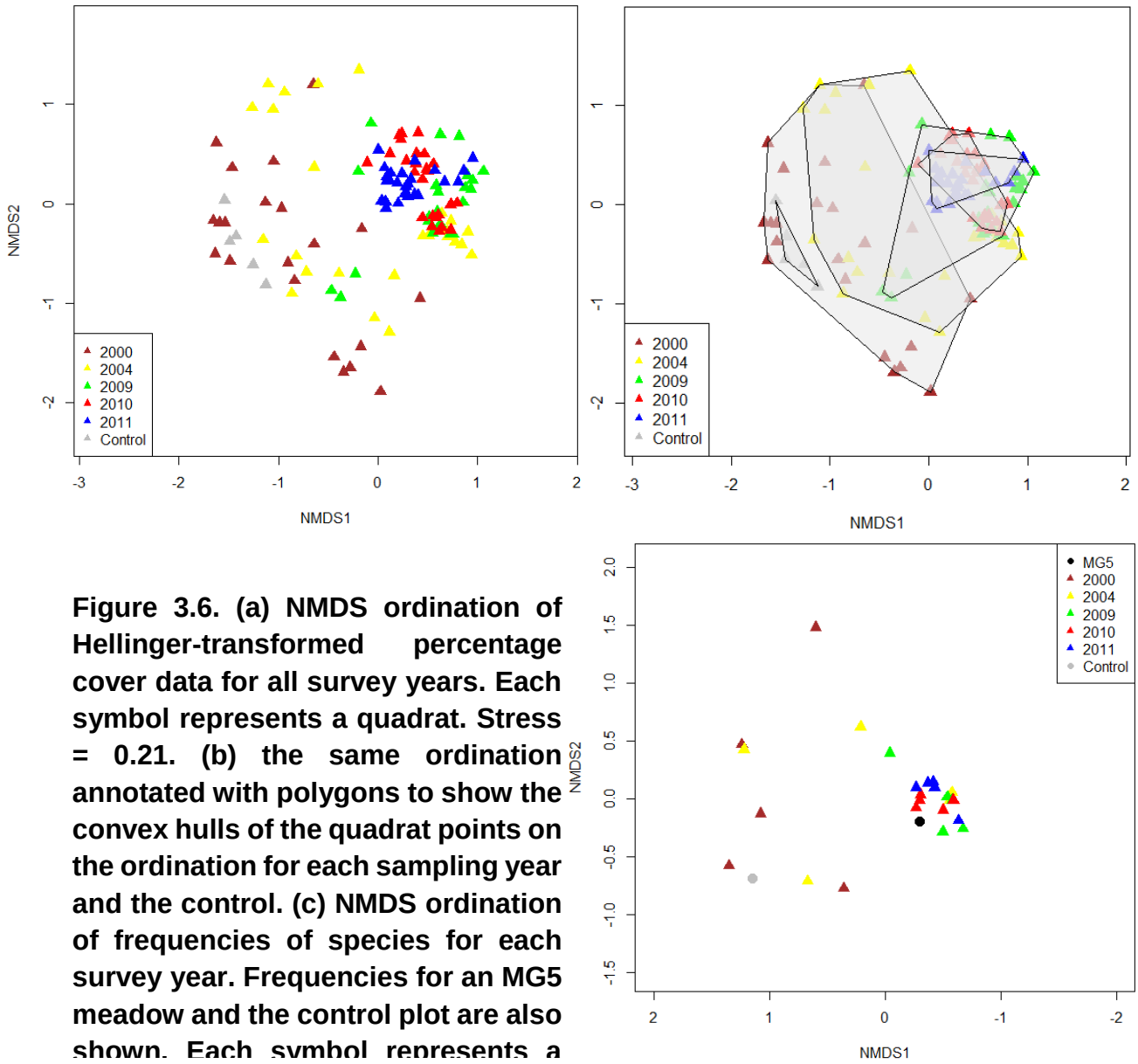

Figure 3.6. (a) NMDS ordination of Hellinger-transformed percentage cover data for all survey years. Each symbol represents a quadrat. Stress = 0.21. (b) the same ordination annotated with polygons to show the convex hulls of the quadrat points on the ordination for each sampling year and the control. (c) NMDS ordination of frequencies of species for each survey year. Frequencies for an MG5 meadow and the control plot are also shown. Each symbol represents a

The NMDS ordinations (Figure 3.6) show differences between the composition of the meadows in the earlier sampling years (2000 and 2004) and that of the meadows in the later years (2009, 2010 and 2011). The meadows sampled in 2009-2011, and

particularly in sampling years 2010 and 2011, have a similar composition to each other and to the typical MG5 meadow. There is a distinct separation between the control plot and the meadows sampled in 2009-2011.

Table 3.2 Changes in NVC affinity of the meadows using the MAVIS vegetation analysis software, and the total number of species found over the study period. % MPS = MAVIS percentage similarity, Rich. = Richness.

	2000			2004			2009			2010			2011		
Field	**NVC**	**% MPS**	**Rich.**	**NVC**	**% MPS**	**Rich.**	**NVC**	**% MPS**	**Rich.**	**NVC**	**% MPS**	**Rich.**	**NVC**	**% MPS**	**Rich.**
A	OV27	42.1	13	MG9A	39.5	16	MG5A	46.5	28	MG5A	47.1	31	MG5A	45.6	29
B	OV27	37.8	14	SD8	34.9	15	MG5A	48.9	22	MG5A	50.1	33	MG5A	50.6	42
C	MG1	40.5	9	MG10	36.7	22	MG6	52.6	26	MG5A	54.3	30	MG5A	56.4	34
D	OV27	38.2	16	MG10	41.2	30	MG6	51.3	28	MG5A	52.7	28	MG5A	53.6	38
E	OV27	39.2	20	MG6	40.7	20	MG5B	45.2	33	MG5A	48.8	31	MG5A	50.2	29
Con.	OV27	37.7	12	OV27	38.2	13	OV27	36.4	13	OV27	35.9	12	OV27	36.6	16

Table 3.2 shows that the NVC community changes over time from a ruderal community (OV27) to a mesotrophic species-rich lowland hay meadow community (MG5). Table 3.2 also shows the total number of species recorded in all 5 quadrats. The total species recorded in each field by year are plotted in Figure 3.7. The bar chart shows that there is an increase in total species numbers over time although numbers were lower in Fields A and E in 2011 than in 2010. Numbers of species in the control plot were consistently lower than in the meadows and this field continued to be classified as a ruderal community.

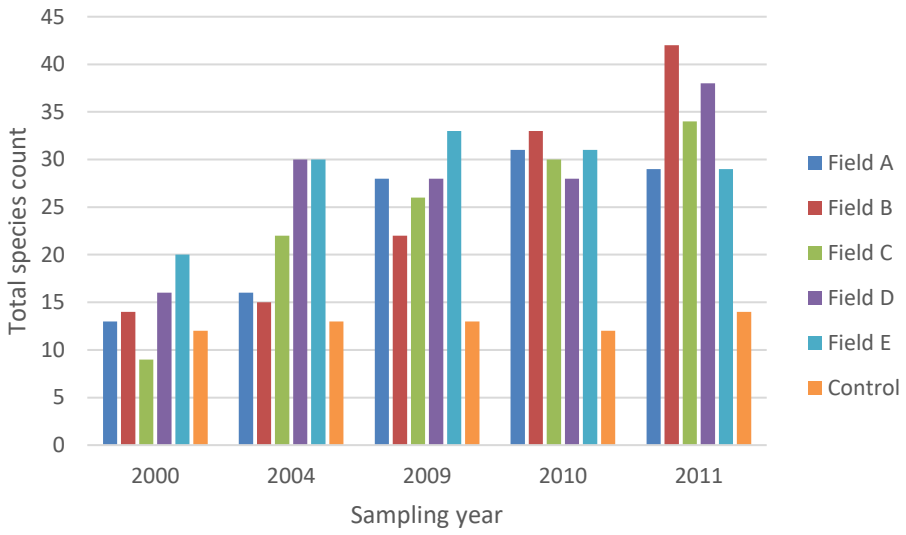

Figure 3.7. Total species recorded per meadow over the sampling years

Figure 3.8 shows that there was an increase in mean Shannon diversity indices for the meadows from 2000 to 2009. Figures 3.9 shows that diversity in grasses and grass-like species fluctuated in some meadows over the sampling period whereas the increase in diversity of forbs (Figure 3.10) reflects the pattern seen in overall species diversity in Fig 3.8. The early results of hay cutting were characterised by a reduction in coarse grassland species such as *A. elatius,* which was found in 10 of 25 quadrats in 2000 but was not recorded in 2009-2011. These grasses have been replaced finer-leaved species such as *Festuca rubra* L. (found in 2 quadrats in 2000 and in 16 quadrats in each year from 2009-2011) and *Agrostis spp.* which showed a similar increase. Soon after the instigation of the hay cutting *Melilotus officinalis* became dominant, increasing from a frequency of 4 quadrats in 2000 to 17 quadrats in 2009. However, the frequency and percentage cover then decreased, and *M. officinalis* was recorded at a frequency of 7 quadrats in 2011.

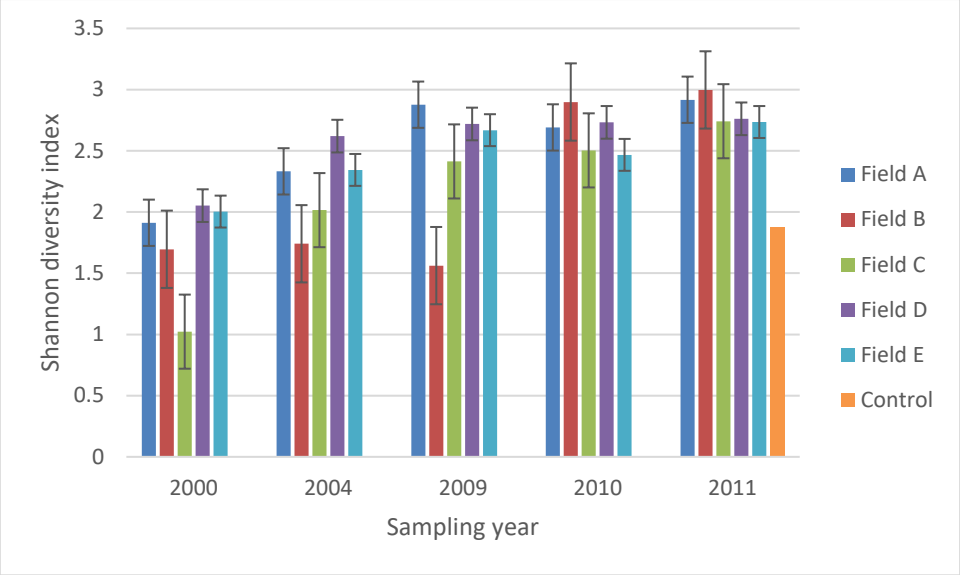

Figure 3.8 Mean Shannon diversity values by sampling year for all species. Error bars reflect standard deviation.

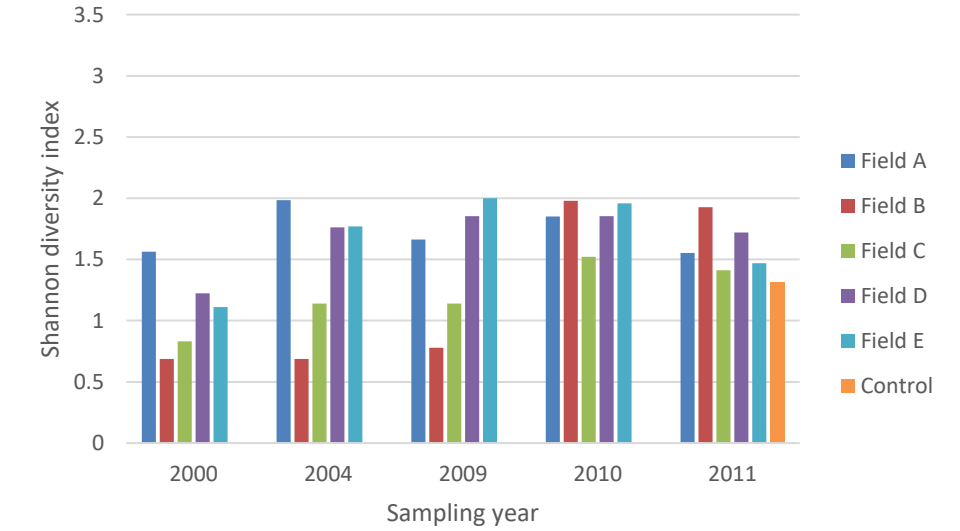

Figure 3.9 Mean Shannon diversity values for grass-like species

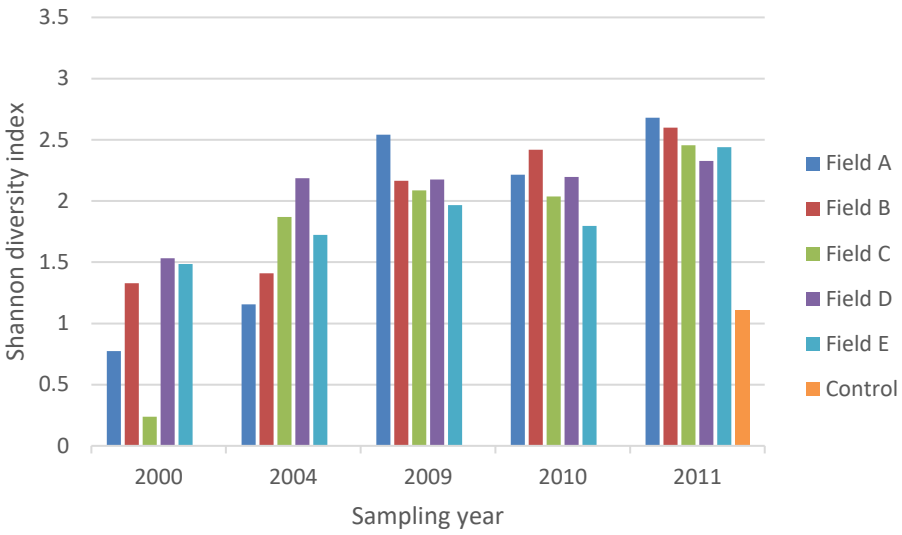

Figure 3.10 Mean Shannon diversity values for forbs

Figure 3.11 shows that MG5 species showed an increase from 2000 to 2004 and remained at a frequency of 30-35 species in the following years. Increases in frequency and percentage cover of some of the constant MG5 species, such as *Lotus corniculatus* L. and *Centaurea nigra* L. were recorded over the sampling period. The frequency of non MG5 species did not follow the same pattern as the MG5 species. However, there were decreases of species typical of unmanaged or ruderal habitats such as *Cirsium spp, Urtica dioica* L. and *Rubus fruticosus agg* sens lat. and increases in species of conservation interest, not listed as typical MG5 species in the NVC, such as *Dactylorhiza incarnata* (L.) Soó, *Dactylorhiza. Praetermissa* (Druce) Soó, *Dactylorhiza fuchsii* (Druce) Soó and *Ophrys apifera* Huds.

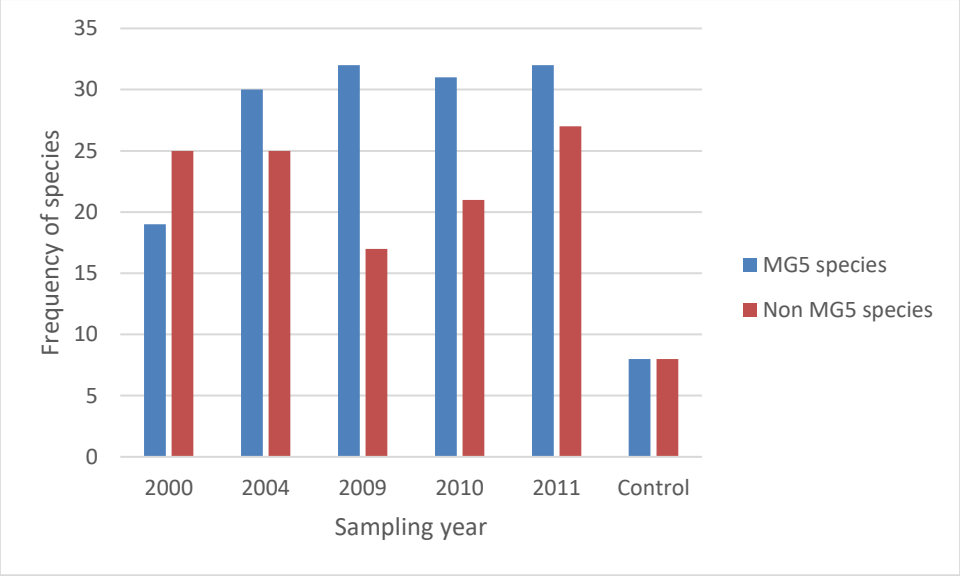

Figure 3.11 Frequency of MG5 and non MG5 species by sampling year

After the sowing of *R. minor* in 2004, this hemi-parasite was quick to colonise (Table 3.2) and its presence coincides with a significant increase in diversity and the number of MG5 species (Figs 3.8-3.11). The NMDS ordinations in Figure 3.6 show that from the date of the introduction of *R. minor* the meadows became much more similar to the target MG5 hay meadow. The control plot shows no such trend and remains with much the same affinities as in the first year of the study.

3.8 Discussion

This study has shown that the introduction of a hay-cutting regime and addition of the hemi-parasitic herb *R. minor*, to sites which were previously sown with a commercial meadow seed mix, has enabled the development hay meadows of conservation value when compared to the criteria of the UK NVC. The establishment of non-planted species into the meadow sward over the study period added to the diversity of the meadows and has allowed them to develop a local character as exemplified by the recruitment of *D. incarnata, D. praetermissa, and O. apifera.*

There has been a progression from ruderal weed communities dominated by tall, coarse grasses, such as *P. arundinacea* and *A. elatius*, to meadow communities. These ruderal grassland communities, such as the OV27 community of the NVC, are common on the synanthropic brownfield sites in the Wigan area, regardless of prior treatment, thus seeded areas and non-seeded areas appear to develop the same ruderal vegetation type. The lack of management leads to a build-up of thatch under the grasses in which only the tougher species such as *Dactylis glomerata* L., *A. elatius* and *P. arundinacea* can maintain their populations (Klimeš *et al*., 2000). The grasses responded in the first years of the management process, changing in their composition, with the coarse grasses being removed and an increase in finer hay meadow species. Grass species such as *Poa trivialis, Anthoxanthum odoratum* and *Festuca rubra* replaced the ruderal species which has been found to happen in grassland systems when mowing is introduced after a period without management (Wilson and Clark, 2001).

Increases in forb diversity and species richness were recorded following the addition of *R. minor* seed to the meadows. There is evidence that the introduction of *R. minor* into species-poor grasslands has led to an increase in forb species and a decrease in grass biomass (Bullock and Pywell, 2005) and a study of root hemi-parasites, including *R. minor*, found that there was a positive association between hemi-parasite species and species richness. *R. minor* was included in the original seed mix but it colonised more successfully when it was added in 2004 following four years of hay cutting and scarification of the ground. Scarification has been shown to be effective in enhancing the establishment of *R. minor* and has been associated with increased species diversity in species-poor grasslands (Westbury *et al*., 2006), and the establishment of *Rhinanthus spp* was not successful in grasslands with high fertility or which were not mown regularly (Mudrák *et al*., 2014).

Desirable MG5 herbs including *L. corniculatus*, *Centaurea nigra* and *Leontodon hispidus* L. have become established in the meadows. These species were part of the original seed mix, so it is possible that they may have been present in the seed bank. However, some studies have shown that grassland seedbanks may not be very persistent (Bekker *et al*., 2000; Wallin *et al*., 2009). Other meadow species such as *Lathyrus pratensis* L., *Vicia cracca* L. and *Knautia arvensis* (L.) Coult. are now present in the meadows which were not in the original seed mix which indicates that there is evidence of recruitment from the local environment. At the same time species such as *Filipendula ulmaria* (L.) Maxim. and *Galium verum* L., which were in the original seed mix and are also relatively common locally, were not recorded in any of sampling years. This could be a result of unsuitable soil conditions or poor dispersal abilities despite being in the environs.

The soil parameters recorded here differ from the range of published values for BAP priority grasslands (McCrea, 2004; Critchley *et al.,* 2002). Levels of extractable P and exchangeable K in such grasslands are typically in the range 0.4–1.1 mg/g and 7.6–21.0 mg/g respectively, and pH levels range from pH 6–6.4. The meadows at Wigan showed lower P and K and higher pHs. Presumably this reflects the synthanthropic influence on the soil with insufficient time for a typical meadow soil to develop. The variation in meadow soil characteristics with Fields 1, 2 and 3 differing from 4, 5 and the Control is also likely to be a product of the ex-industrial history of the site. Deposition of industrial waste, whether boiler ash, coal spoil or PFA, can be highly localised, subsequently leading to the differing soil chemistry of the various meadows. The difference in edaphic conditions on the Wigan Flashes meadows may limit recruitment of some species.

Dispersal plays a key role in restoration with spatial isolation impeding success (Helsen *et al*., 2013). Waldén *et al*. (2017) recorded an increase in grassland specialists over time in sites which had been restored 6-23 years before their study but, identified the significance of a local species pool in neighbouring semi-natural grassland fragments as a source of propagules.

Colonisation of target meadow species may occur after several years but only at a small scale within a meadow (Burmeier *et al*. 2011). Other studies have shown herbs to persist well when they do establish, but are more variable in their establishment and spread than grasses (Jongepierová *et al*., 2007; Pakeman *et al.,* 2002; Pywell *et al*., 2003). The continued recruitment of unsown herbs into the sward is key in the

development of the meadow grasslands and adds to their local distinctiveness. This process of colonisation has not been repeated in the unmanaged control plot.

There are however some notable omissions from the existing community that would be found in a traditional hay meadow. For instance, there were no records of *Carex* species in any of the study meadows. Fine-leaved *Carex* species have been identified as representative species of ancient grasslands (Karlík and Poschlod, 2009; Forey and Dutoit, 2012) but have not become well established in restored grasslands even after sowing (McDonald, 2001), so it is unsurprising that they are not present in the study sites. Dispersal of seeds is affected by many factors including dispersal mechanisms. Animal dispersed seeds have the potential to travel kilometres compared with the few metres typical of unassisted or wind dispersed seeds (Coulson et al. 2001; Thomson et al. 2011). Even if seed rain does fall on the grasslands there is no guarantee of establishment. Edpahic factors at the site may be unsuitable and competition from established species may also prevent colonisation (Fry *et al*.; 2017). In particular a group of early colonising species were the most significant architects of target species establishment. These species, which included *Trifolium pratense* (red clover) and *Ranunculus acris* (meadow buttercup), were seen to be more influential than soil chemistry or the microbial community, and could affect success for several years. It has been suggested that a phased approach to grassland restoration, initially sowing *R. minor* to reduce the effect of competitive species, followed by seeding with specialist plants is the best approach (Pywell *et al.,* 2007). It may now be worth considering sowing the absent MG5 species. Alternatively it may equally be worthwhile continuing to monitor the site and documenting changes in meadow communities.

With such limited numbers of traditional lowland hay meadow resources remaining in the UK and in other European countries, the development of new hay meadows on synanthropic sites, could be a way to create these valuable wildlife habitats. If they are managed consistently, to an appropriate management plan, the desired direction of ecological travel can be achieved.

In the example studied here the utilisation of the Countryside Stewardship agri-environment scheme has been shown to deliver the Habitat Biodiversity action plan outcomes. The use of agri-environment grants was crucial in creating a more sustainable grassland system and achieving both Species and Habitat Action Plan targets akin to those achieved elsewhere on non synanthropic systems (Ovenden *et al.,* 1998; Bayliss *et al.*, 2003).

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Chapter 4 - The habitat preferences of Willow Tit in Britain in a landscape with a stable population.

4.1. Abstract

The Willow Tit (*Poecile montanus kleinschmidti*), has undergone a rapid decline in the UK. Habitat variables explaining wood patch occupancy and habitat selection within woodlands across a landscape in Northwest England within an apparently stable population were examined. We quantified Willow Tit presence/absence using a tape lure within woodlands and scrub habitats. Site occupancy was found to be positively correlated with dead wood, positively associated with scrub willow species and negatively associated with the proportion of primary canopy trees. Willow Tits tended to be found in scrub woodland, growing on post-industrial sites with impeded drainage, and were almost completely absent from woodlands with tall primary canopy species.

Within secondary woods, Willow Tits were found in areas with high scrub growth (trunk diameter, between 12 cm and 30 cm). Habitat management to benefit this species will need to maintain extensive areas of diverse secondary scrub woodland with high water tables, together with dead wood, in areas currently occupied by Willow Tits.

4.2. Introduction

The British sub-species of Willow Tit, (*Poecile montanus kleinschmidti* Conrad von Baldenstein, 1827), has undergone one of the most rapid declines of any British bird in recent decades as measured by the number of breeding pairs. Analysis of Breeding Bird Survey (BBS) data shows it has declined by 83% between 1995 and 2012, which is second only to the Turtle Dove (*Streptopelia turtur* Linnaeus, 1758) in degree of

long-term decline of all the birds monitored via the BBS (Harris *et al*., 2014). The UK (United Kingdom) population was estimated at 3400 territories in 2009 (Musgrove *et al*., 2013). Over a similar period, its breeding range has contracted significantly. The 2007-11 atlas shows a breeding range decline of 50% since the 1988-91 atlas and an almost complete loss from the southeast of England (Balmer *et al*., 2013). To date, the reasons for this decline are still largely unexplained.

Further afield, declines have also occurred in Europe, with an overall population decline, of 40% in Finland and 53% in Sweden since 1990 involving the subspecies *borealis*. The French population of the subspecies *rhenana* has declined by 50% during the same period (Lewis *et al*., 2007). However, the British race appears to occupy different habitats to the coniferous forest of those found in Europe. In Britain the Willow Tit is generally found in damp, early successional woodland, particularly in patches of Elder (*Sambucus nigra* L.), Alder (*Alnus glutinosa*. Gaertner 1791) and Birch (*Betula* sp.) scrub and in riparian woodlands often at the edges of wetlands. They also nest in urban areas, especially in marginal scrub around gravel pits and flashes (Cramp *et al*., 1993; Baillie *et al*., 2001).

Siriwardena (2004) proposed several possible reasons for the rapid decline of Willow Tits, which included loss of dead wood for nesting, competition from expanding populations of Blue Tits (*Cyanistes caeruleus* Linnaeus, 1758) and Great Tits (*Parus major* Linnaeus*,* 1758), predation pressure from increasing numbers of predator species, such as woodpeckers, and a decline in habitat quality with changes in climate and management, leading to the drying of their favoured wet woodlands.

The Willow Tit is the only British Tit species to excavate a new nest hole each breeding season. This is positioned less than a metre above the ground in a rotten stump (Cramp, 1993). A reduction in standing dead wood, suitable for nesting Willow Tit, would be a possible explanation for the national decline. However, sympatric Blue Tit and Great Tit have been observed to oust them from these holes (Maxwell, 2002), and both competing species have undergone population increases in recent years (1995-2012: Blue Tits +5% and Great Tits +43%, Harris *et al*., 2014). Potential predator species, especially the Great Spotted Woodpecker (*Dendrocopos major* Linnaeus, 1758), have also increased in abundance (1995-2012: GSW +139%, Harris *et al*., 2014).

Siriwardena (2004) analysed 30 years of national Common Bird Census survey data and showed that, in terms of habitat, Willow Tit were most common in wet habitats, and that in such habitats there was no significant decline in their numbers. However, significant declines were associated with woodland and farmland habitat. Furthermore, across all habitats there was no significant relationship between Willow Tit numbers and the abundance of possible competitors, and only in the little used farmland habitat was there a significant relationship between lower numbers of Willow Tit and greater numbers of Great Spotted Woodpeckers. Siriwardena (2004) concluded that, as no relationship could be found to support competition or predation hypotheses, woodland habitat degradation might be the most likely cause of the decline. Increased grazing by deer in woodlands over recent years has removed much of the understory, so the loss of this important foraging area for Willow Tit may be a possible reason for their decline (Newson *et al*., 2012). Recent studies have shown

that the species is retreating to areas that are cooler and wetter (Oliver, 2017), which includes the Wigan study area.

Complementing this broad national approach, studies by Lewis *et al*. (2007, 2009) have addressed the question at a local scale by looking in greater detail at sites where Willow Tits occur. Lewis *et al.* (2007) in southeast England, where the Willow Tit decline has been particularly strong, examined whether there were habitat differences between woods that were occupied by Willow Tits or those that had been abandoned by them. Again, no evidence was found for the competition or predation hypotheses; numbers of potential competitor and predator species were not significantly different at occupied and abandoned sites. Moreover, no difference in a range of habitat features, including tree number and size variables, dead wood, canopy height and vegetation cover were found. The only significant difference found between occupied and abandoned sites was soil moisture content, which was higher at occupied sites (Lewis *et al.,* 2007).

Lewis *et al*. (2009) studied an apparently stable Willow Tit population in the East Midlands of England, comparing occupied and unoccupied woodlands for a wide range of vegetation characteristics. Willow Tits were more likely to be found in woods <25 years old, with high levels of soil moisture and with vegetation cover between 2-4m high. This, with the observation that Willow Tits tend to feed low in the canopy, usually in the shrub layer (2-4m, Perrins, 1979).

In contrast to these observations, results of an extensive survey of woodland birds throughout Britain found that sites were more likely to have retained or gained Willow Tits since the 1980s if they had a low tree basal area, a large maximum tree diameter, low understory cover (4-10m), and low moss cover (Amar *et al.,* 2006). This indicates that Willow Tits persist in woods with large trees.

Of the four hypotheses put forward by Siriwardena (2004), habitat quality is the one currently with greatest empirical support, but the nature of such quality remains obscure. There is clearly a need for more work to study the habitat preferences of the Willow Tit, particularly in areas with relatively stable populations. The present study seeks to address this need by studying the stable populations in Northwest England. Here the populations tend to be associated with the many post-industrial (brownfield) sites, which are characterised by early successional woodland, poor drainage, and water bodies. We aim to characterise the woodland variables associated with site occupancy and habitat selection within occupied woods across the landscape.

4.3. Method

4.3.1. Study sites

All the public access woodlands in the study area of Wigan Borough with were identified for surveying (Figure 4.1) and they were known to support a stable population, since confirmed by a similar survey in 2016 (Hollins *et al*, 2018). A range of woodland types were surveyed, including primary canopy woodland, riparian woodlands and secondary scrub habitats. The development and management of the woodland patches in Wigan Borough was known, as the borough has a history of restoration of the brownfield post-industrial areas within the region (Champion and Ashton, 2010, 2011).

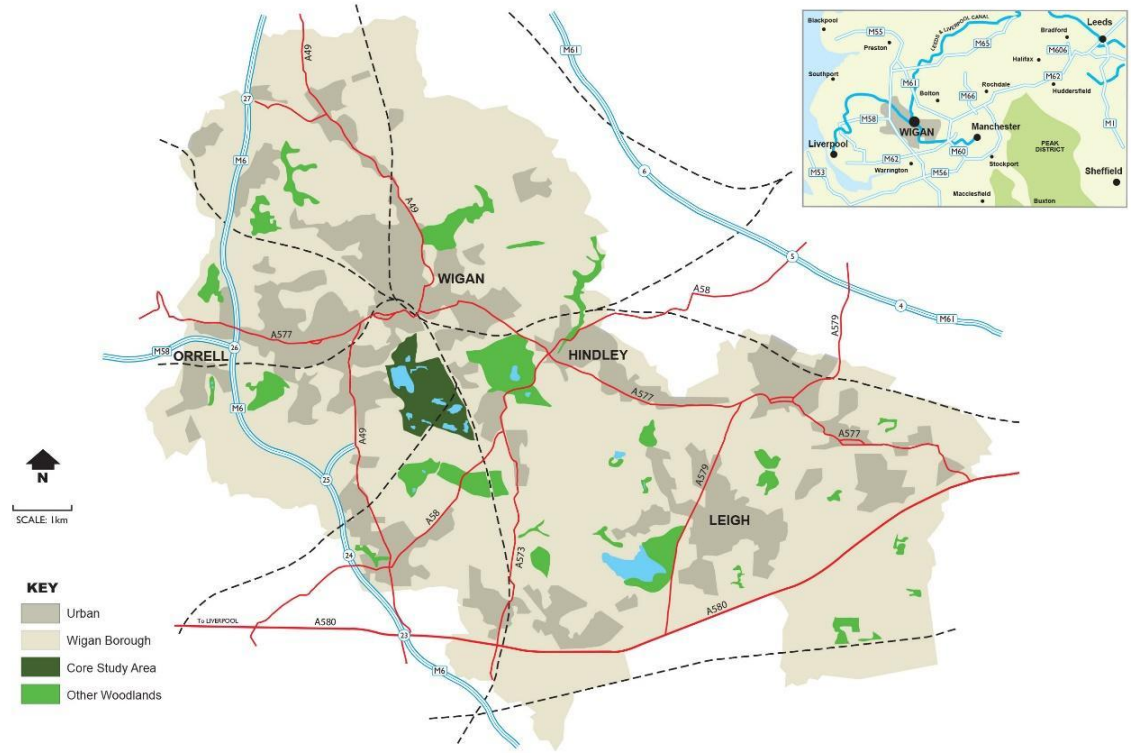

Figure 4.1. Map showing the study area in Northwest England.

4.3.2. Bird surveys

The 19 woodland sites were surveyed across the Wigan Borough in Northwest England during the Willow Tit breeding season from 1st April and 30th May, 2010. Willow Tits were surveyed during daylight hours, avoiding days with rain or strong winds. As Willow Tits begin excavating their nest holes during April (Snow and Perrins, 1998), any bird in an occupied site was considered to be a potential breeder. In line with previous studies (Lewis *et al*., 2007, 2009), the survey utilised a tape lure technique with a pre-recorded Willow Tit. When played back, the song could be heard by the surveyor up to 70m from the playback point. Playback stations were placed approximately 140m apart, to reduce the likelihood of duplicate records of the same birds. Tape luring took place from paths at each site and routes were selected to cover the woodland habitat. Larger woodlands would have more survey points; the number of survey points in a woodland ranged from one to twelve (with a mean of five). At each station the lure was played for a maximum of 2 minutes or until Willow Tits responded by either calling or singing back or were seen approaching and inspecting the station.

GPS (Global Positioning System) points were recorded at each playback station; each station was recorded as a 10-figure grid reference using a Garmin Fortex 301 GPS, which is accurate to within 5m of recording location. The date, site location, the presence or absence of Willow Tits and a range of environmental factors were recorded, including tree species, primary canopy height, secondary canopy height, and trunk diameter.

On each visit, other potential breeding woodland birds were recorded, either heard singing or seen; to allow for a comparison between the woodland types and tree species used by Willow Tit and other species, including potential competitors.

4.3.3. Habitat surveys

Woodland habitat variables were recorded within a 25m radius with the playback station at the centre. Within this area percentage cover of primary canopy, secondary canopy and standing dead wood were recorded. The primary canopy was defined as mature trees within one layer and secondary canopy was defined as understorey below a primary canopy or small trees (<10m height) without a high forest canopy. Tree species composition was recorded by listing all species within the 25m radius. Canopy characteristics were also recorded by measurement of trunk DBH (diameter at breast height), calculated as the mean of three randomly selected trees within both the primary and secondary canopies. Standing dead wood or deadwood attached to living trees was recorded as a percentage of total standing trunks within the woodland.

The percentage of organic matter in the soil was analysed from a single sample taken from the survey point, following the method of Rowell (1994). QGIS v2.16 was used determine measurements of the woodland area and perimeter.

4.3.4. Analysis

The data were found to have a normal distribution when tested, so the statistics were run on the original, untransformed data set. Canonical Correspondence Analysis (CCA) was used to identify the relationships between bird species distribution and

woodland variables for the 19 woods studied using the *vegan* package in R version 3.3.2 (R Core Team 2016). The significance threshold was set at $p < 0.05$ based on Crawley (2012). Canonical Correspondence Analysis (CCA) allows species abundances to be related to to environmental variables (Ter Braak, 1986). CCA is widely used in this type of study (eg Kmeci and Denac, 2018; Li et al 2019). All other calculations were also undertaken in R version 3.3.2 (R Core Team 2016).

4.4. Results

Over the whole survey area, 188 Willow Tits were recorded in 14 of the 19 woodlands (Table 4.1). Site areas ranged from 0.3ha to 80ha and habitat was measured at 188 Willow Tit survey points.

Mapping Willow Tit across the study area also shows proximity of territories with streams, rivers and other wetlands (Figure 4.2). There was no significant correlation between woodland size and Willow Tit density (Spearman Rank P = 0.926, rho = -0.023; no fig shown). However simple ring buffering of the known nesting pairs at 250m, based on an average territory size of 500m radius from the nest, (Cramp, 1993; Siffczyk *et al*., 2003) and comparing this to a map of potential suitable habitat (woodland), showed that it was unusual to find gaps of over 250m between territories.

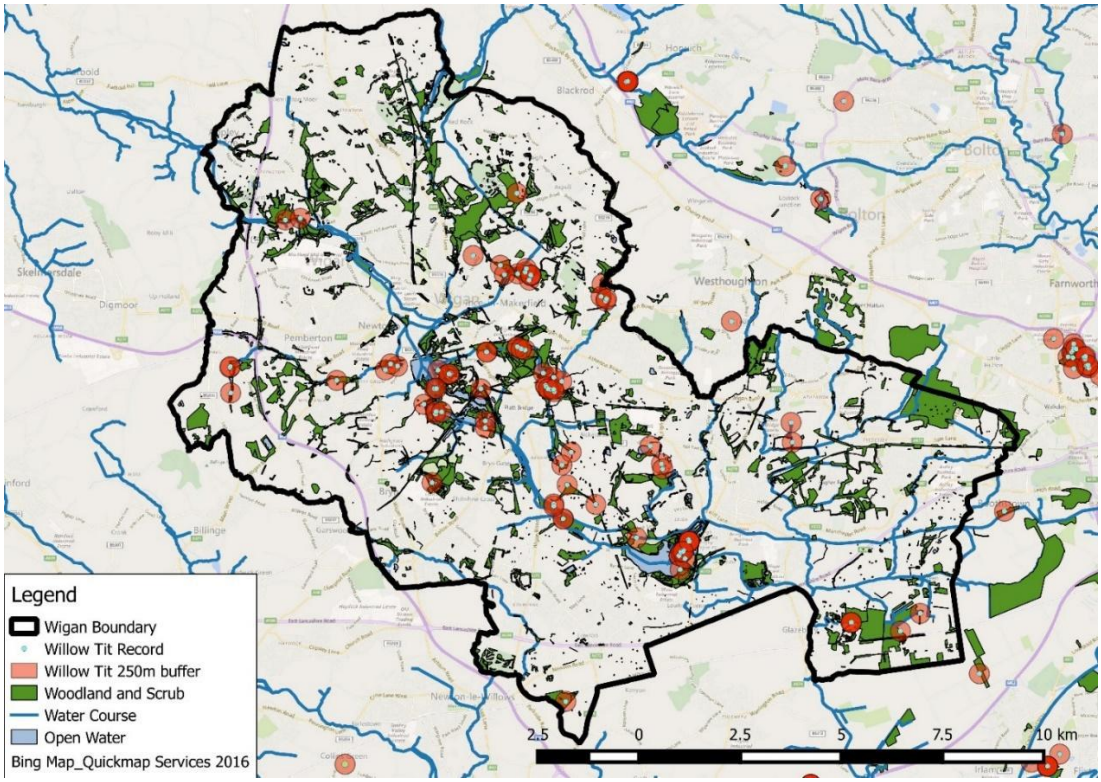

Figure 4.2. GIS Analysis of Willow Tit Records, collected during the stud period, investigating spatial distribution especially in relation to water courses and woodland areas. (The darker a ring the greater the density of Willow Tit pairs in that location).

Table 4.1. Characteristics of the 19 woodlands in the Wigan study area, (measured April and May 2010), showing the factors that may influence the density of willow tit pairs.

	Soil organic matter (% dry weight)	Primary canopy cover (%)	Secondary canopy cover (%)	Dead wood (%)	Mean primary canopy DBH (%)	Mean Secondary scrub DBH (cm)	Number of subunit component woods	Total wood Perimeter (meters)	Total wood area (ha)	Willow Tit density (Prs ha^{-1})
Amberswood	13.3	48.6	46.1	9.3	54.8	23.1	14	17671	79.6	0.13
Abram Woods	8	57.5	14.2	19.2	44.7	13.7	6	8527	0.9	0
Abram Flashes	13.3	31.8	37.4	8.2	67.7	24.2	6	15815	23	0.08
Bickershaw	3.7	40	23.3	5	31.9	11.4	5	1792	0.4	0.01
Borsdane	6	70	24.3	10.6	362	20.3	3	7314	27.1	0.2
Gathurst Woods	80.1	58.2	26.5	15.6	64.8	61.9	3	11013	20.2	0.82
Haigh	7.8	53.3	40.6	9.3	123.1	29.3	1	6876	71.2	0
Kingsdown	7	8	64	10	21.9	152.6	1	1059	0.3	0.01
Lilford Woods	6	0	66.7	5	0	34.7	1	493	0.6	0
Low Hall	6	100	48.9	27.5	76.8	50.5	4	1389	3.7	0.75
Lady Mable's	2.7	70	10	2.5	23.3	12.3	1	1282	9.1	0
Leigh Woods	10.1	48.9	29.7	16.4	58.3	20.2	4	3771	26.7	0.1
Orrell Brick Works	7	33.4	43.2	16.1	62.9	33.2	1	873	4.2	0.98
Orrell Water Park	8.4	38.2	55.3	17.9	22.8	44.3	1	1269	0.5	1.1
Pennington Flash	11.1	68.8	42.5	26.3	69.8	21.5	3	3108	4.1	0.02
Three Sisters	9.5	64.9	35.1	15.3	56.7	20.5	1	1269	10.2	0.49
Victoria Fields	8.1	55	10	5.8	35.3	10.9	1	2714	11.5	0.41
Virador wood	4.9	27	30	7	16.4	18.8	1	2509	20.8	0
Wigan Flashes	7.4	54.6	36	15.5	52.2	21.2	24	18214	69.5	0.7
MEAN	**11.6**	**48.9**	**36.0**	**12.8**	**65.5**	**32.9**	**4.3**	**5629.4**	**20.2**	**0.3**
ST.DEV	**16.8**	**23.2**	**16.3**	**7.0**	**76.9**	**32.0**	**5.7**	**5946.4**	**25.5**	**0.4**

The CCA (Figure 4.3) shows that Willow Tits occur in very different woodland compared to the other species. Willow Tits show a clear affinity with sites that have a high percentage dead wood, high secondary canopy cover, and relatively low secondary tree diameter. They tend to occur away from older, high canopy woodland (characterised by high primary canopy percentage and primary tree trunk diameter values) and were usually absent from such woods. Soil organic content is a small vector in this analysis and appears to show little affinity with any of the bird distributions.

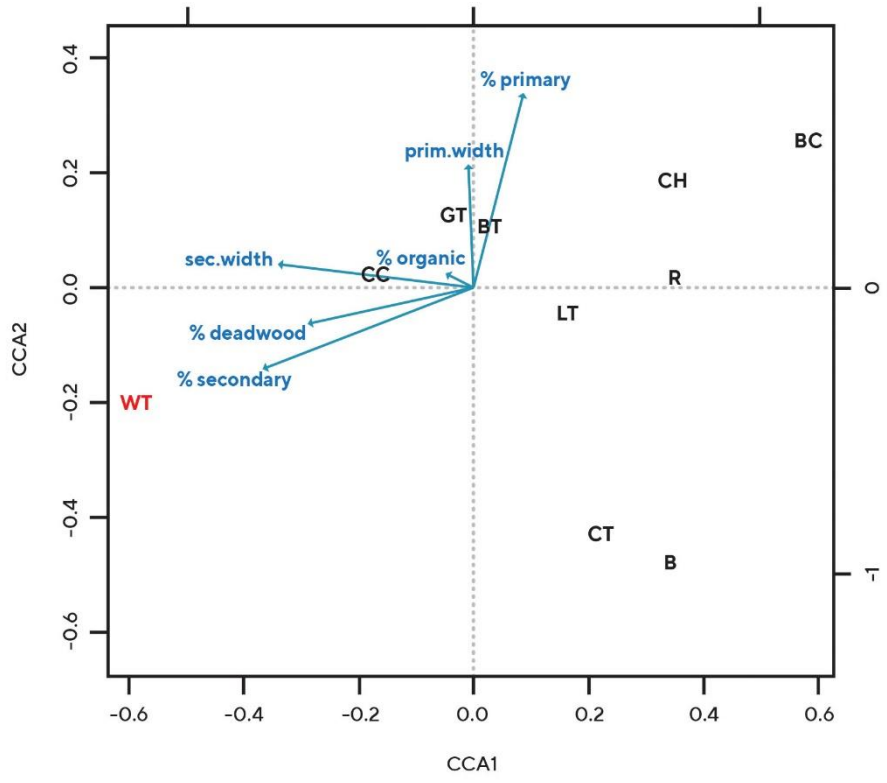

Figure 4.3. CCA of woodland bird associations with measured physical factors, recorded from the whole Wigan Borough survey area April-May 2010. Bird species are given by standard BTO (British Trust for Ornithology) code letters as follows: B, Blackbird; BC, Black Cap; BT, Blue Tit, CC, Chiffchaff; CH, Chaffinch; GT, Great Tit; LT, Long tailed Tit; R, Robin; WT, Willow Tit.

Table 4. 2 Trees recorded in willow tit survey areas

Alder	*Alnus glutinosa* (L.) Gaertn.
Ash	*Fraxinus excelsior* L.
Beech	*Fagus sylvatica* L.
Birch	Mainly *B pendula Roth. x B pubescens* Ehrh.)
Crack willow	*Salix fragilis* L.
Elder	*Sambucus nigra* L.
Field Maple	*Acer campestre L.*
Goat Willow	*Salix caprea* L.
Grey Willow	*Salix cinerea* L
Hawthorn	*Crataegus monogyna Jacq.*
Hazel	*Corylus avellana L.*
Holly	*Ilex aquifolium* L.
Poplar	*Populus* L. spp.
Oak	*Quercus robur* L.
Rhododendron	*Rhododendron ponticum* L.
Rowan	*Sorbus aucuparia* L.
Sycamore	*Acer pseudoplatanus* L.

Seventeen tree taxa were recorded from the survey area (Table 4.2). Analysis of the tree community composition utilised by the various bird species shows Willow Tits are separated in the ordination from many other woodland birds, particularly other tit species, and show an association with the soft timbered secondary scrub species,

particularly with Grey Willow (*Salix cinerea* L.) and Crack Willow (*S. fragilis* L.) (Figure 4.4) although Elder (*Sambucus nigra* L.), Hawthorn (*Crataegus monogyna* Jacq.), Rowan (*Sorbus aucuparia* L.) and Hazel (*Coryllus avellana* L.) are all found as part of the preferred woodland assemblage. The tendency for Willow Tits to avoid areas with tall canopy trees is clear. Figure 4.3 shows that willow tit is much less common in the woodlands containing larger trees of the hard-wooded species including Oak (*Quercus spp.*) and Beech (*Fagus sylvatica* L.).

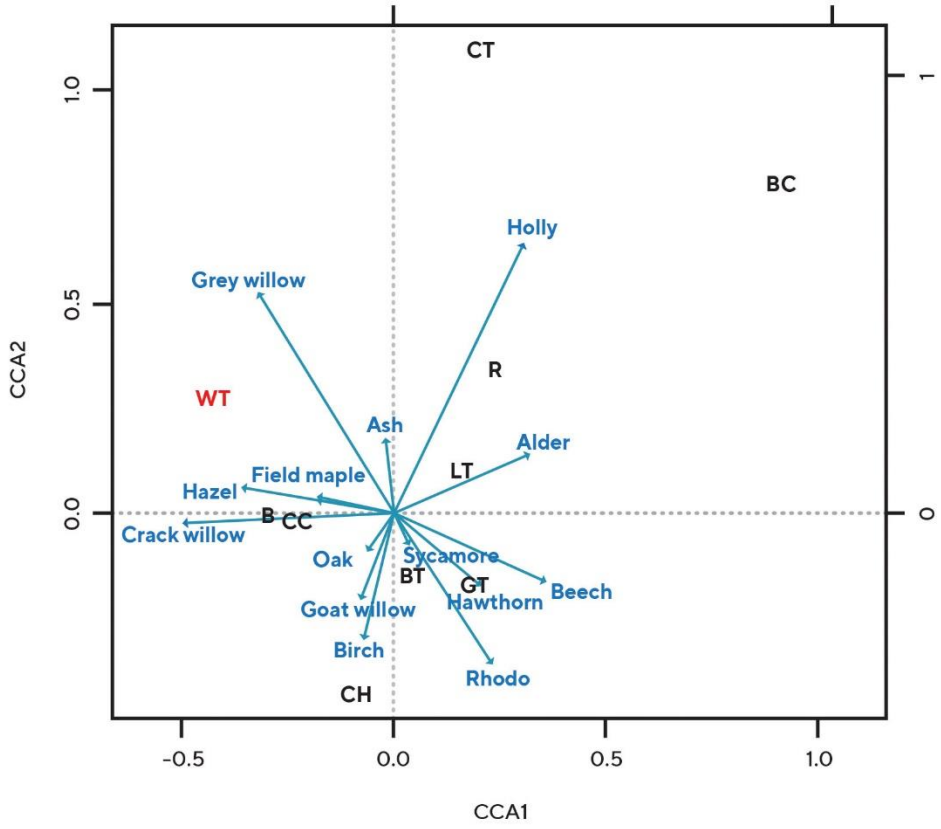

Figure 4.4. CCA of Willow Tit association with secondary scrub tree species comparing this to other passerine species recorded during the study. Bird species are given by standard BTO code letters as follows: B, Blackbird; BC, Black Cap; BT, Blue Tit, CC, Chiffchaff; CH, Chaffinch; GT, Great Tit; LT, Long tailed Tit; R, Robin; WT, Willow Tit.

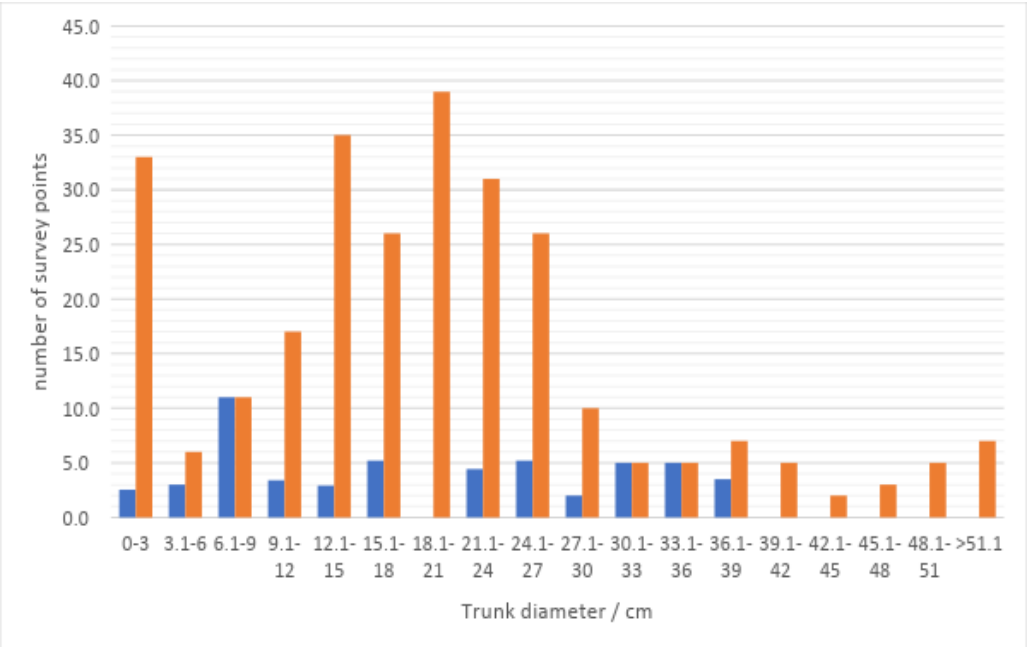

Figure 4.5. Primary canopy tree diameter at all survey points within the Wigan Borough study area. Blue bars show study points where Willow Tits were recorded, orange bars show all study points.

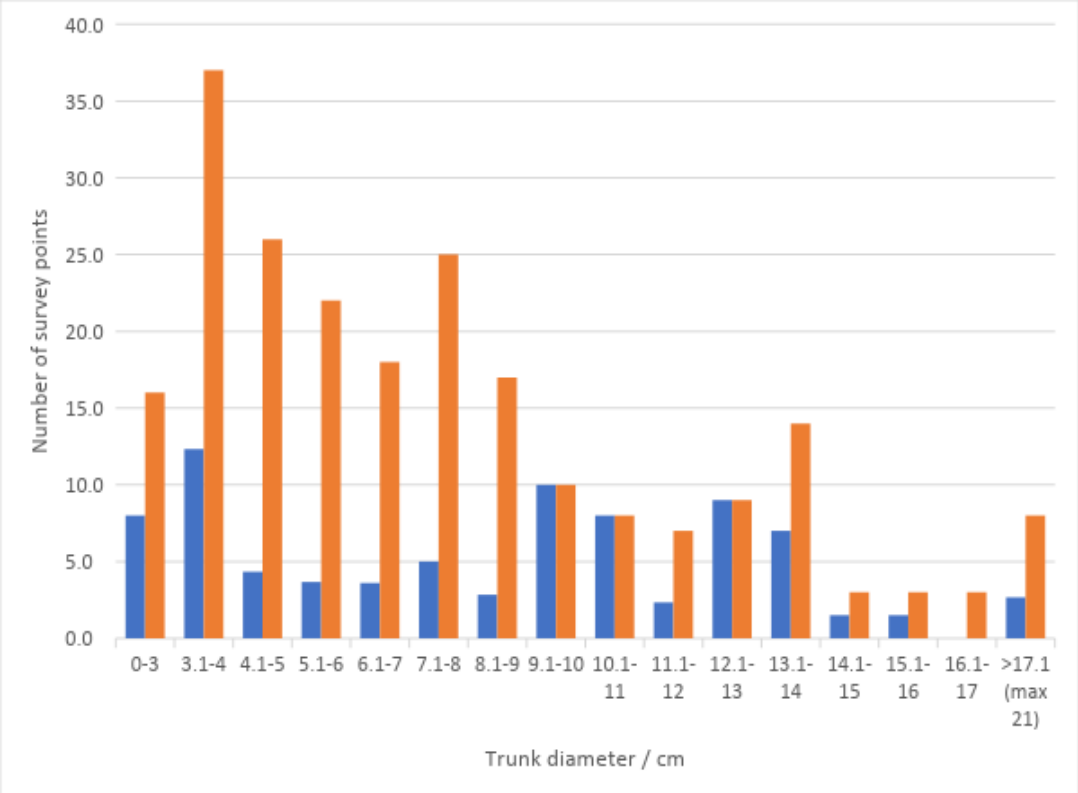

Figure 4.6. Secondary scrub tree diameter at all survey points within the Wigan Borough study area. Blue bars show study points where Willow Tits were recorded, orange bars show all study points.

The diameter of trees in both the canopy and the secondary layer shows the species preference for smaller diameter trees (Figures 4.5 and 4.6). Willow Tits were recorded at locations where the mean primary canopy tree DBH was below 40cm while the survey points with high Willow Tit occupancy had secondary scrub trees in the range of 9.1-13.0cm DBH.

4.5. Discussion

The area chosen for the study has a relatively stable population (S Atkins, Greater Manchester Ecology Unit, pers. com), this was confirmed in a repeat survey using a similar methodology in 2016 in which a total of 224 Willow Tits were recorded. The apparent stability of the Willow Tit population in the study area may be due to the landscape scale of the available habitat, which is found in regular patches over a total of 30km^2. In addition, there are linking corridors between the patches of woodland scrub. This post-industrial landscape of the Wigan Borough supports an estimated 8% of the UK population of Willow Tits.

In this apparently stable population, Willow Tits were more likely to be found in younger woods (<25 years old), with high levels of soil moisture and with scrub between 2-4m high, feeding low in the canopy, usually in the scrub layer. Similar results were found by Lewis *et al*. (2009). However this study showed no Willow Tits in open woodlands with little scrub and large canopy trees in contrast to the results of Amar *et al.* (2006).

Willow Tits are associated with early successional stage deciduous woodland. A wood was more likely to be occupied if trees were of a smaller diameter, dominated by smaller scrub species and with over 15% of the trunks being standing dead wood.

These secondary scrub woodlands, consisting of soft-timbered trees such as Grey Willow, Crack Willow and Elder with a relatively quick life cycle and high mortality (Risely *et al*., 2008), provide the dead wood required for nesting by this species.

The small diameter timber, below 40cm DBH, found in the woodlands used by nesting Willow Tits equates to trees of up to five metres tall; trees of this height were considered the primary habitat for Willow Tits by Perrins (1979) and Lewis *et al.* (2007).

Primary canopy woodlands seem to provide little secondary scrub growth and often negligible standing dead wood within the smaller diameter size preferred by Willow Tit. The woodlands with larger tree diameters tend to have a lower density of tree trunks and are more open below their high canopy. The reasons why canopy woodland is less utilised by Willow Tits has been explored elsewhere (Amar, 2006; Lewis *et al*., 2007); in the study area most of the tall canopy woodland did not have a full secondary scrub zone, due to the shading effects of the larger trees and past management practice. Willow Tit presence had a strong association with an understory of dense scrub within the woodland. The woodlands typical of post-industrial sites, both those planted during land restoration in the 1970s and 1980s and those where natural regeneration has been the governing factor in woodland development, are dominated by dense scrubby vegetation, usually with a large amount of soft-timbered species.

The importance of standing dead wood has been clearly shown in the present study, whereas this relationship has not always been shown elsewhere (Lewis *et al*., 2007). No efforts were made to investigate the suitability of the dead wood for Willow Tit nesting, although the decay state of the timber is probably of great importance, as suggested by the numerous of test holes observed, created by Willow Tits before a

fully excavated nest is made. It was also noted that a significant proportion of Willow Tit nests are created in dead timber where the nest is excavated in the horizontal or near horizontal plane utilizing dead branches as well as the more traditional view of vertical standing dead wood. The locations of nests, and the condition of the dead wood used would add significantly to our knowledge of the species. The woods utilised by Willow Tits are dominated by quick-growing, soft-timbered species, whilst there is little use by pairs of woodland dominated by taller, harder-timbered species, such as Oak and Ash. Where oak and ash dominated woodlands were occupied, such as Borsdane and Haigh, the birds occupied scrub patches on the periphery of the main woodland. This was also seen in Perrins (1979), Snow and Perrins (1998) and Amar (2006).

In addition to the post-industrial nature of the landscape, there are many areas in low lying locations where the woodlands remain damp throughout the year. This has encouraged secondary scrub to colonise and dominate many of the areas that were formerly mining, peat extraction and other similar sites. Soil water content has been shown to be higher at occupied sites compared to sites that have recently been abandoned by Willow Tits (Lewis *et al*., 2007) and based on mapping, the distribution of Willow Tits across the study area shows some linkage with streams, rivers and other wetlands, and the damper soils associated with them.

Thus, while the study patch size did not affect the use of a woodland by Willow Tits, the connectivity of woodland blocks appeared to be important. The availability of suitable habitat, the regular distribution of the woodland blocks, and the connectivity via river and wetland corridors all contribute to maintaining the species population. Furthermore, beyond the study area the adjacent landscapes of Warrington, Salford

and St Helens extending over 54km^2 have a similar post-industrial heritage and supports more of the willow scrub on a truly landscape scale.

Consideration of other woodland bird species (Figures 4.3, 4.4 and 4.5.) suggested that both Blue Tit and Great Tit, are more common in the taller primary woodland, occupying a different habitat to the Willow Tit. Competition with Blue Tit and Great Tit does occur in the study area, as annually a number of Willow Tit nests are taken over, primarily by Blue Tits (personal observation), other tit species have been widely reported to oust Willow Tit from their nests (Maxwell, 2002), and this behaviour may contribute towards the habitat separation observed. Both Siriwardena (2004) and Lewis *et al*. (2007), suggested that the presence of other tit species did not contribute to the national decline of Willow Tits. However, Siriwardena (2004) looked at rural setting, where separation by habitat was more clearly defined, in the peri-urban areas typified by this study nest site competition may be more important than in some of the more rural areas previously studied; as in these peri-urban locations that we find a wide use of nest boxes in both community nest box schemes and within gardens adjacent to the areas utilised by Willow Tit.

Undoubtedly, the cool and wet climate typical of the north west of England (Oliver, 2017) contributes to the success of the species in the study area. The average annual rainfall of 836mm (Met Office) and associated humidity helps the standing timber to decay in such a way that it is available for nesting Willow Tits. The current range of willow tit is in line with predictions based on climate change (Leech *et al.,* 2004) which suggested a north-westward shift in the range of this species and the loss of populations in the south of the UK.

4.5.1 Management

This study proposes that to aid the conservation of Willow Tit, scrub woodlands should be planted in suitable areas alongside watercourses and in other predominantly damp areas, developing regular well-connected patches of the habitat within the landscape. The species of the trees used and the planting arrangement of this mix should allow some development of woodlands suitable for Willow Tits to be created. These species would include Grey and Crack Willow, but can contain other species such as Rowan, Hazel, Birch and Hawthorn.

The development of a dense scrub woodland is important, so the trees should be closely planted to provide structure as the woodland develops. The addition of a supply of standing deadwood is important; the authors have had success with stumps placed within developing woodlands to increase the available deadwood resource, this information has been shared widely and is used by a conservation bodies working on Willow Tit conservation

As our findings show that Willow Tits favour early successional stage woodland, habitat management needs to be focused on protecting areas of scrub currently occupied by Willow Tits. Stands of willow scrub should be managed to ensure that a sufficient area of young growth is retained.

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Chapter 5 - Systematics and conservation of *Dactylorhiza* (Orchidaceae) on synanthropic sites in the Northwest of England.

5.1. Abstract

Conservation of complex taxa within groups known for hybridisation and introgression may be best served by management approaches aimed at maintaining genetic diversity, especially if taxa are adapted to synanthropic or other disturbed habitats. In the United Kingdom, the Marsh-orchids, *Dactylorhiza,* are a complex group, currently divided into eight species. However, there have been uncertainties and conflicting views concerning the taxonomic treatment of these taxa. In Northwest England, in a band between Liverpool and Manchester, there are populations of Marsh-orchids growing on synanthropic sites that have been placed variously as *Dactylorhiza praetermissa* or a hybrid of *D. praetermissa* and *D. purpurella*. To address this issue, living specimens of *D. praetermissa* and *D. purpurella* were studied *in situ* in the north and south of England, where any hybridization was extremely unlikely, along with samples from populations in Northwest England on synanthropic sites (Wigan Marsh-orchid) and one on ancient grassland. The study investigated variation in morphological characters comparing the unidentified orchid populations with those of known identification. Analysis of variance showed significant differences between taxa, with the research populations intermediate to *D. praetermissa* and *D. purpurella.* Principal Components Analysis (PCA) was unable to provide support for the parentage of the very variable Wigan Marsh-orchid. The one population on ancient grassland showed strong affinity to *D. praetermissa*.

The author suggests that the Northwest populations of orchids on synanthropic land are distinct and show probable gene flow between *D. praetermissa* and *D. purpurella*. The conservation of Wigan Marsh-orchid is best served by continuing current management practices that allow gene flow to occur.

5.2. Introduction

Conservation is often associated with individual, rare species, such as those on international or national Red Lists, or those locally rare (Cheffings and Farrell, 2005; BSBI, 2018; IUCN, 2018). However, professionals working in ecological sectors recognise that the conservation of such species requires consideration beyond just populations of the species, to include maintaining genetic diversity, conservation of their communities and suitable habitats. Maintaining biodiversity in a changing climate, alongside increasing urbanisation, pollution, changing land use and loss of habitat, might require promotion of alternative approaches.

Indeed, under conditions of rapid change, a species ability to adapt might be crucial. Plants have shown, for example, rapid adaptation to damaged habitats, such as heavy metal tolerance in grasses (Gregory and Bradshaw, 1965; Antonovics *et al.,* 1971; Antonovics, 1972). Ability to adapt is facilitated by genetic diversity (e.g: Garant *et al*., 2007; Frankshaw et al, 2014), therefore management activity that allows such diversity to be maintained and enhanced should be encouraged. Such a simple aim is complicated by the realities of plant species boundaries. Whereas some plant taxa have relatively fixed species boundaries, other groups are more fluid with hybridisation

and introgression potentially increasing genetic diversity (Reiseberg *et al*., 2000; Reiseberg *et al*., 2003, Zou *et al.,* 2017).

In addition, there is a considerable body of evidence that synanthropic habitats and those with recent disturbance history provide novel or intermediate niches that are often colonised by hybrids from a wide range of plant groups (e.g. Lamont *et al*., 2003; Mahelka *et al.,* 2007; van Hengstum *et al.,* 2012; Ortego *et al*., 2017; Zhang *et al.,* 2018).

Therefore, we need approaches to maintain diversity so that rare and scarce plant taxa can evolve and adapt to changing conditions. Conservation strategies to maintain the evolutionary processes generating biodiversity and adapted taxa are rarely considered in conservation, although it would be beneficial in complex, hybridising groups and would develop further evolutionary understanding (Ennos *et al*., 2005). However, it can be viewed as controversial to promote conservation of hybrid taxa. Bohling (2016) argued that, should ongoing hybridisation pose a risk to the purity of a rare of a threatened species, then management plans might include actively removing hybrids. He also recognised that hybridisation was not always a risk and sometimes the level of hybridisation was low. Therefore, there are opposing views regarding conservation for hybridising taxa and the need to understand the context and plant group under consideration is important.

One family with complex relationships among taxa is the Orchidaceae, one of the two largest angiosperm families with over 25,000 species (Chase *et al*., 2015; Fay, 2016). Orchids are a charismatic family, many species have attractive flowers (Fay *et al*.,

2015). Hybridization and hybrid speciation have led to challenges in stabilising the generic level classification and the number of genera continues to rise each year, with 736 recognised genera in 2015, as delimitations are re-assessed as the result of new research (Chase *et al*., 2015; Fay, 2016). Indeed, Orchidaceae has been shown to have the highest propensity for hybridisation amongst plant families (Whitney *et al.,* 2010). It has been suggested that widespread hybridization and, to a lesser degree, ploidy variation, are factors that combine to overcome the adaptive disadvantages of apomictic (i.e., asexual) reproduction, driving ecological-niche divergence among reproductive systems (Mau *et al.,* 2015).

The Marsh-orchids within genus *Dactylorhiza* are a complex group that have been subject to recent taxonomic changes due to advances in molecular studies. These studies have provided insight to relationships between the diploid and tetraploid species, hybridisation, polyploid evolution and origins of tetraploids (e.g. Devos *et al*., 2006; Chase *et al*., 2007; Pillon *et al*., 2007; Bateman and Denholm, 2012; De hert *et al*., 2012).

According to Stace (2010), eight main species of *Dactylorhiza* can be found growing in Britain. However, *Dactylorhiza* are notoriously difficult to identify due to extreme variation in colour and morphology, and there have been other taxonomic approaches, such as that followed by Hedrén *et al*. (2007). Stace (2010) considers that *Dactylorhiza* is represented by two diploid lineages; *D. fuchsii* (Druce) Soó, *D. incarnata* (L.) Soó, one autotetraploid; *D. maculate* (L.) Soó, thought to be derived from a diploid species in the *D. fuchsii* lineage, and a range of allotetraploids derived from various hybridisation events between *D. fuchsii* and *D. incarnata,* or possibly on occasions

between *D. maculata* and *D. incarnata* (Table 5.1). Some authors treat the allotetraploids as subspecies of a single named taxon, *D. majalis* (Rchb.) P.F. Hunt and Summerh. (Hedrén *et al.,* 2011)*,* but most authors recognise a variable number of taxa in the group, varying in morphology and ecology, these include; *D. traunsteinerioides* (Pugsley) R.M. Bateman and Denholm, *D. kerryensis* (Wilmott) P.F. Hunt and Summerh.*, D. purpurella* (T and T.A. Stephenson) Soó, *D. ebudensis* (Wiefelspütz ex R.M. Bateman and Denholm) P. Delforge and *D. praetermissa* (Druce) Soó (Stace, 2010)*.*

Further complications have arisen as the result of genetic research which demonstrates that some of the named allotetraploids have been formed from the parental lineages multiple times, and plants with consistent morphology and ecology do not necessarily form coherent genetic groups. For instance plants named *D. traunsteinerioides* are often more closely related to other allotetraploids in the same region than they are to *D. traunsteinerioides* from other regions (Devos *et al.,* 2006; Pillon *et al.,* 2007; Balao *et al.,* 2016**)**. Bateman and Denholm (2012) place *D kerryensis* and *D. ebudensis* as subspecies of *D. traunsteinerioides*.

Table 5.1. *Dactylorhiza* species and ploidy level in the British Isles as listed in Stace (2015).

***Dactylorhiza* species**	**Ploidy**	**Chromosome number (2n)**
D. fuchsii	Diploid	80
D. incarnata	Diploid	40
D. maculata	Autotetraploid	80
D. praetermissa	Allotetraploid	40
D. purpurella	Allotetraploid	40
D. ebudensis	Allotetraploid	80
D. traunsteinerioides	Allotetraploid	80
D. kerryensis	Allotetraploid	80

Orchidaceae are often found in manmade habitats and amongst the most common colonizers of secondary habitats in temperate Europe are *Dactylorhiza*. These orchids are species with short life cycles and broad ecological amplitudes (Adamowski, 2006). The complex variation within the *Dactylorhiza* genus has led to a number of recent taxonomic and hybridisation studies (Devos *et al.,* 2006; Pillon *et al.,* 2007; Bateman and Denholm, 2012; Balao *et al.,* 2016). Morphological techniques have frequently been adopted to investigate the relationships within the *Dactylorhiza* (e.g. Roberts, 1966; Adcock *et al*., 1983; Shipunov and Bateman, 2005). Hybrids frequently present characters intermediate between parental taxa, although novel characteristics and hybrid vigour can occur which allow colonisation of disturbed ground and more diverse habitats than the parent species (Gramlich *et al.,* 2016).

In Northwest England, in Bolton and Wigan, variable and distinctive populations of *Dactylorhiza* can often be found growing on synanthropic sites across a wide pH range (Gemmell, 1977; Crompton, 2008). It has been suggested that the variation between populations within the study area is due to the differences in soil composition (Adcock *et al*., 1983; Shaw, 1997; Crompton, 2008).

These populations have been variously described as Northern Marsh-orchid *D. purpurella*, the Southern Marsh-orchid *D. praetermissa* or a hybrid of these two taxa, given that the area is within the overlap zone of the two species (Deleforge, 1995). Greenwood & Gemmell (1974) suggested the occurrence of presumed hybrid swarms at site in the area, including the Wigan Flashes (Westwood Power Station). In comparison Adcock *et al.* (1983) showed that the populations are morphologically very variable and that individual populations could be attributed to be either *D. purpurella* or *D. praetermissa,* although acknowledging that hybridisation may have led to modification of some of the morphological characters. Artificial crosses that produce viable F_1 hybrids are recorded between *D. purpurella* and *D. praetermissa* (Roberts reported in Stace, 1975), although there are no records of hybrids between *D. purpurella* and *D. praetermissa* in the study area (Stace *et al.,* 2015). It may therefore be expected that hybridization and introgression are likely along this overlap zone (Stace *et al.,* 2015). Thus synanthropic sites are generating populations exhibiting variation which in turn provides the raw material for evolution to act upon.

This study develops the research by Adcock *et al.* (1983) by considering whether the Wigan marsh orchids can be easily assigned to one of the two species *D. purpurella* or *D. praetermissa*, or if the populations should be considered as potential hybrid taxa. The amount of time that has elapsed since each site has been disturbed and the different substrates is also considered.

The framework for this study is the view of Ennos *et al*. (2005) that in complex groups such as the Orchidaceae, conservation is best served by allowing the evolutionary dynamics to continue. From a land manager's perspective, management to maintain

orchid diversity is important, however if the taxa are not easily classifiable, allowing evolutionary processes to persist may be the pragmatic solution.

The study sites are currently in conservation management by The Lancashire Wildlife Trust and two local authorities, Wigan and Bolton Councils, who have sympathetically managed the grasslands for their flora. Management for the conservation of evolutionary potential would be an interesting addition to the consideration of these sites.

This study sets out to answer the following questions for the 'Wigan Marsh Orchids':

1. Identify morphological differences between *D. purpurella* and *D. praetermissa*.
2. Compare the morphological characteristics of the populations of 'Wigan Marsh Orchid' with those of *D. purpurella* and *D. praetermissa* and hence identify the affinities of the synanthropic populations.
3. Identify the extent of interpopulation morphological variation in the Wigan Marsh Orchids and consider if any differences are linked to substrate type or time since disturbance.

5.3. Method and Materials

This study uses morphological data to compare the *Dactylorhiza* taxa found on the Wigan and Bolton area with known populations of Southern marsh-orchid *D. praetermissa* found in Hampshire, Northern Marsh-orchid *D. purpurella* found in North Lancashire and Anglesey, and populations of orchids from Wigan, found on grassland

that has been cut annually, but otherwise has not been disturbed over the last century and a half in Wigan Cemetery (Table 5.2, Figure 5.1).

The comparison sites were chosen as they were well documented locations for their respective taxa, Anglesey, Sunbiggin Tarn and Orton in Cumbria are recognised sites for *D. purpurella*, whilst the Warnborough Greens, and Farlington Marshes are well known for its population of *D. praetermissa*. Hook Heath is a known to be the site of hybrid *D. purpurella* X *D. praetermissa* = *Dactylorhiza* X *insignis* (Stace *et al*., 2015). Thursley Common is included as a reference population of Early Marsh-orchid *D. incarnata*. These sites are both on historically undisturbed, traditionally managed grasslands SSSIs, maintained by conservation organizations.

Other members of the genus, *D. maculata, D. fuchsii*, and *D. traunsteinerioides,* were excluded as putative parents due to colour, leaf spotting and structure, whilst both *D. ebudensis* and *D. kerryensis* are species with limited distribution that are not in the study area and have distinctive characters (Stace, 2010).

5.3.1. Site descriptions and plant selection

Data were collected from *Dactylorhiza* orchids at eleven sites (see Figure 5.1 and Table 5.2). All sites visited consisted of areas >1 ha and all were managed habitats. The Wigan Flashes to the south of Wigan town centre is a synanthropic site with a variety of habitats. This includes grasslands which are growing upon shale deposits left from coal mining. These have established following coverage of the shale with around 100 mm of topsoil, from an unknown source, in the late 1970s. This has been

left largely unmanaged until the last decade, since when an annual hay crop has been taken in late August. Bedford Colliery near Leigh has a similar history and management to the grasslands at the Wigan Flashes. Nob End is a synanthropic site close to Bolton, with vegetation growing upon alkaline waste resulting from the LeBlanc process that was deposited until the early 1900s.

Wigan Cemetery site is a burial ground established in Victorian times and is 400 metres NE from the Wigan Flashes sampling area; the site is undisturbed except for an annual cut in late August/early September. Sunbiggin Tarn SSSI is a predominantly grassland site grazed by sheep, as is the nearby Orton site; The Warnborough Greens site in Hampshire is a hay meadow on a damp grassland SSSI, managed by the Hampshire Wildlife Trust, as are Farlington Marshes and Hook Common. These Hampshire sites all have a mid-summer hay cut.

Thursley Common is valley mire in Surrey, managed for its heath and mire communities by cattle grazing. The Anglesey site is a dune and heathland complex to the North West of the island.

Individuals were randomly sampled during the period June 2012 to 2014. Between 20 and 34 specimens were sampled at each site (Table 5.2) with all samples at any one site being taken in one year. At the reference sites (Hampshire, Thursley, Anglesey, Orton and Sunbiggin) identification was undertaken for each plant based upon criteria given in Stace (2010). Thus any putative hybrids were not sampled at these sites. Likewise damaged orchids were not sampled. At the north-west sites (Wigan Flashes, Wigan Cemetery, Nob End and Bedford Colliery) all individuals were included in the samples. Habitat types were identified using The National Vegetation Classification (NVC Rodwell, 1998; Table 5.2).

Table 5.2. Summary of the eleven survey sites: Grid reference. Sample size, NVC community, and management.

Location and (species*)	Grid reference	Sample size	NVC classification	Management
Warnborough Greens (S)	SU 730 534	30	MG8	Grazing by cattle and ponies
Sunbiggin Tarn (N)	NY 678 076	30	U4b	Sheep grazing
Wigan Flashes (W)	SD 586 033	34	MG5	Annual hay cut in late summer
Wigan Cemetery (W)	SD 590 037	29	MG8	Annual maintenance cut in late summer
Bedford Colliery, Leigh (W)	SD 672 005	30	MG5	Annual hay cut in late summer
Farlington Marsh (S)	SU 684 041	30	MG5	Annual hay cut
Orton (N)	NY 626 082	30	MG3	Annual maintenance cut
Hook Common (S)	SU 730 533	30	MG5	Annual hay cut
Thursley Common (E)	SU 971 647	20	M16	Cattle grazing
Anglesey (N)	SH 223 802	30	M8	Non-intervention
Nob End (W)	SD 749 081	30	CG2	Maintenance cut of scrub

* S = Southern Marsh-orchid, *D. praetermissa*

N = Northern Marsh-orchid, *D. purpurella*

E = Early Marsh-orchid, *D. incarnata*

W = Wigan Marsh-orchid research population

Figure 5.1. Map of survey site locations across the British Isles,

5.3.2. Morphometric measurements

There is a balance in any morphometric study, between the number of characters measured, the number of individuals measured in any population, and the number of populations studied (Shaw, 1997). In this study, the number of characters measured was kept low (nine characters) in order to allow the sampling of sites during the summer flowering seasons (Table 5.3, Figure 5.2). All characters were measured *in situ* without damaging the plants. Floral measurements were recorded to 0.01 mm using a digital micrometer and were measured on the lowermost flowers for consistency. This followed establishment that there is very little between-flower variation on any one individual plant spike using a rolling mean. Other measurements were recorded to an accuracy of 1 mm using a ruler.

Table 5.3. Vegetative and floral characters collected from *Dactylorhiza* individuals.

	Features measured	**Unit**
Plant characters	Total height	mm
	Inflorescence height	mm
Leaf characters	Length	mm
	Width	mm
Flower characters	Labellum width	mm
	Labellum height	mm
	Spur length	mm
Lowest Bract characters	Total length	mm
	Bract length beyond the lowest flower	mm

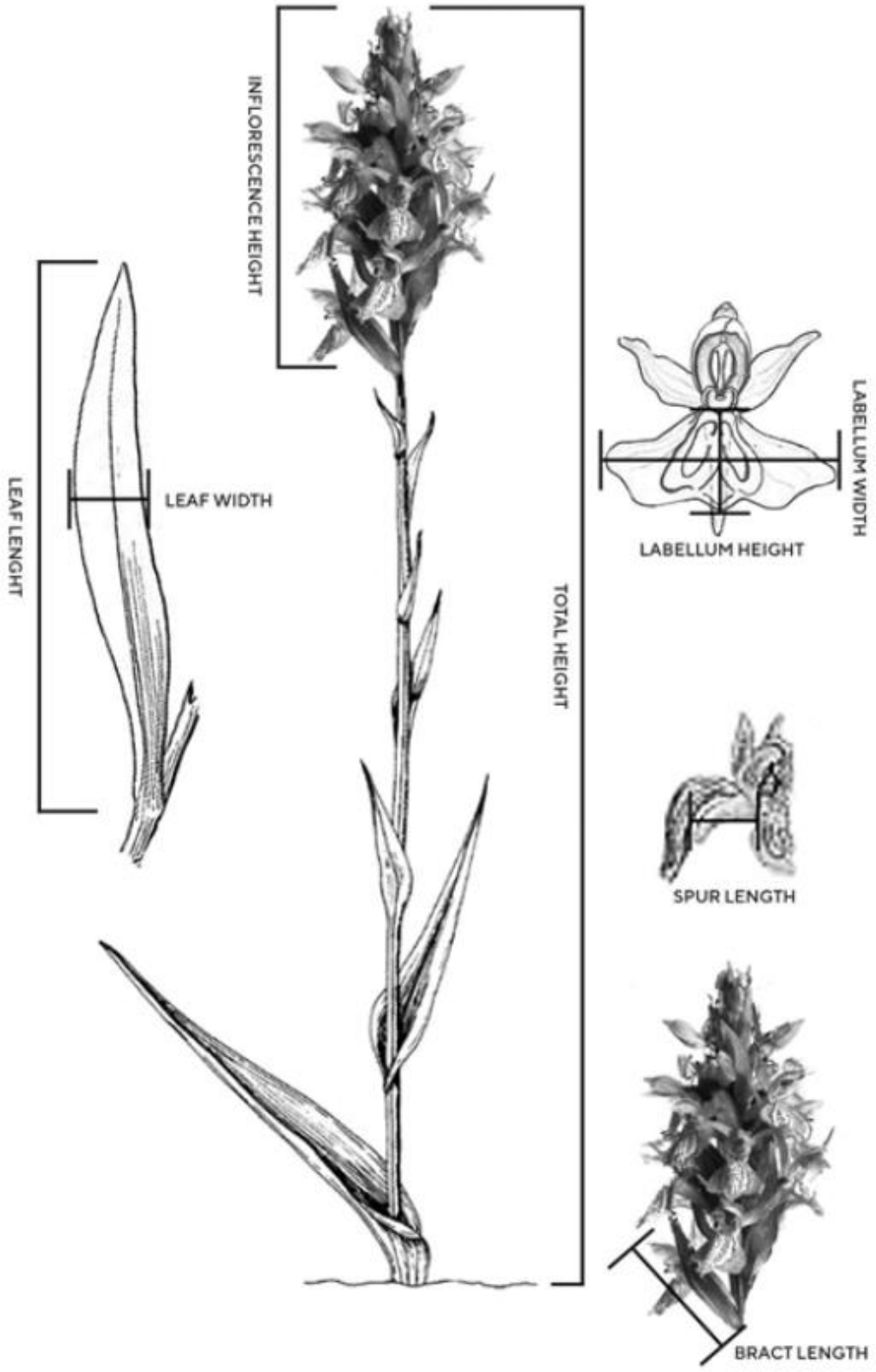

Figure 5.2. Diagram showing the locations of measurements on vegetative and floral components of the *Dactylorhiza* plant.

All statistical tests were carried out in Minitab version 17 (Minitab Inc.). A one-way ANOVA, testing for differences in means at the 0.05 level of significance unless the largest variance was more than 1.5 times the smallest and then Welch's test was used. *Post hoc* tests were Tukey (for ANOVA) and Games-Howell Comparison (for Welch's). Samples were tested for normality using the Anderson-Darling test and a histogram with normal curve plotted displayed. Tests of normality are considered less useful in small samples (less than 30 specimens) (Hair *et al*., 1998). The histograms and normal curves were used in addition to assess actual departure from normality. These indicated that data were normal and no data transformations were necessary.

Multivariate analysis was used to summarize variation patterns (Reinhammar, 1998). Only variables that were significantly different for at least one sample were used in Principal Components Analysis (PCA). Prior to running PCA, all variables were standardised to the range -1 to +1. PCA was run using a correlation matrix. While Hybrid Index analysis (*sensu* Anderson 1936, 1949) is a common morphometric approach to investigating hybridisation it is not appropriate here, reflecting its scarcity in Orchidaceae work. This is because a hybrid index approach requires a series of clearly contrasting characters in the two taxa thought to be hybridising. However in the species considered here quantitative floral and vegetative parts overlap in length and therefore cannot be assigned to one species. Similarly shapes and patterns on floral parts are difficult to score as they are variable and overlapping.

5.4. Results

At each site putative hybrids and other orchid species occurred. At the Hampshire sites both *D. incarnata* and *D. fuchsii* were recorded, at Sunbiggin *D. incarnata* and *Gymnadenia conopsea* were present, and at all four Wigan and Bolton sites *D. incarnata* and *D. fuchsii* orchid were known to occur.

Although previously Wigan Marsh-orchid populations have been considered as *D. praetermissa, D. purpurella* or a hybrid of *D. praetermissa* and *D. purpurella* (see Introduction), because *D. incarnata* is found at Wigan Cemetery, preliminary analyses were carried out to examine whether *D. incarnata* was involved in the hybridisation events forming the Wigan Marsh-orchid populations. One-way ANOVA tests at 0.05 significance level were carried out to examine the possible parentage *D. praetermissa* x *D. incarnata* for the Wigan Marsh-orchids. Results (not shown) for six of the nine variables indicated that the Wigan orchids were not intermediate between these two species. A PCA of the same three groups did not place Wigan Marsh-orchids in an intermediate position, thus indicating that *D. incarnata* was not one of the parental species. Moreover hybrids of both *D. incarnata* x *D. praetermissa* and *D. incarnata* x *D. purpurella* are occur as individual specimens (Stace *et al*., 2015), not as an extensive population as is found with the Wigan Marsh-orchid populations. Thus results indicate that Early Marsh-orchid *D. incarnata*, was not involved in hybridisation at these locations, and is thus excluded from subsequent analyses. The Hook Heath data were also discarded at this stage as this population was revealed to be the sole extra-limital population of hybrid *D. purpurella* and *D. praetermissa* (Stace *et al*., 2015). This was unknown to the authors at the time of data collection.

Question 1. Are all populations of Wigan Marsh Orchids similar?

The means for Wigan Cemetery population sample were significantly different from all the other Wigan Marsh-orchid samples for four of the nine variables (Table 5.4), the Wigan Cemetery sample was significantly taller / longer for each of these variables (Plant height, Leaf length, Bract beyond flower, Lip length). Results for a further three variables placed Wigan Cemetery in the longer / wider group (Total bract length, Lip width, Inflorescence height) and intermediate in only one variable (Spur length). There was no significant difference in Leaf width means between the samples.

Post hoc tests for the other three samples placed Wigan Flashes and Nob End in the same group and intermediate in size for five variables; Bedford Colliery was significantly shorter in plant height, but otherwise was not significantly different from at least one other of the Wigan Flashes or Nob End samples (Table 5.4).

This indicated that the Wigan Cemetery sample was dissimilar from the other three; specimens were generally taller with longer / wider characters than the other Wigan Marsh-orchid samples.

Due to the significant morphological differences and differences in habitat, the Wigan Cemetery sample was separated out and not included in Wigan Marsh-orchid group that was tested for hybrid origin (Question 3). However, because the Wigan Cemetery sample was typically taller / wider than the rest of the Wigan group, it presented characters more typical of *D. praetermissa*. Therefore, it was further examined for affinity with that taxon (see Question 4).

Table 5.4. ANOVA or Welch's test for character differences between Wigan and Bolton research Marsh Orchid populations. Means followed by the same letter are not significantly different at 0.05 level. Letter A is allocated to the longest measurement and letters in bold indicate significant difference for the variable.

Dactylorhiza species	Population	Stat	Plant height /mm	Leaf width /mm	Leaf length /mm	Total bract length /mm	Bract beyond flower /mm	Lip width /mm	Lip length /mm	Spur length /mm	Inflorescence height /mm
Wigan Marsh orchid	Wigan Flashes	Mean	241.26 **B**	27.06 A	108.82 **B**	27.87 **A**	10.10 **B**	8.35 **AB**	7.55 **B**	7.23 **C**	77.79 **A**
		St. Dev	71.01	7.24	23.71	5.03	5.14	1.39	0.99	0.92	23.18
Wigan Marsh orchid	Nob End	Mean	256.73 **B**	26.80 A	120.60 **B**	22.53 **BC**	9.46 **B**	8.84 **A**	6.34 **C**	9.96 **A**	67.43 **AB**
		St. Dev	66.57	9.87	22.43	5.22	4.51	1.46	0.77	2.33	26.98
Wigan Marsh orchid	Bedford Colliery (Leigh)	Mean	195.30 **C**	23.53 A	116.40 **B**	21.39 **C**	8.52 **B**	7.56 **B**	6.72 **C**	7.95 **BC**	60.37 **B**
		St. Dev	59.79	5.47	22.29	4.69	3.99	1.12	0.92	1.38	15.18
Wigan Marsh orchid	Wigan Cemetery	Mean	325.72 **A**	25.52 A	156.03 **A**	25.95 **AB**	14.04 **A**	8.91 **A**	8.29 **A**	8.38 **B**	67.53 **AB**
		St. Dev	66.09	6.10	37.64	5.24	4.69	1.61	1.17	1.30	17.29

Question 2. Are there differences between *D. purpurella* and *D. praetermissa* orchids for the variables measured?

Significant differences were found for seven out of the nine biometric variables between known populations of *D. purpurella* and *D. praetermissa* (Plant height, Leaf length, Total bract length, Bract beyond flower, Lip width and length, Inflorescence height) (Table 5.5). Means for the *D. praetermissa* sample were always taller / wider than the *D. purpurella* sample means, although there were overlaps in ranges. This provided support that there were morphological differences between these two species for the variables measured, and that these variables could be used to aid separation of the species.

Among the two *D. praetermissa* populations there were no significant differences between means for three variables, and the Warnborough Green sample was significantly taller / wider than Farlington Marsh for the remaining six variables.

There were no significant differences among the three *D. purpurella* populations between means for three variables. For five of the remaining variables there were no significant differences between two of the samples, only for plant height did all three

samples have significantly different means. Orton was the tallest, Anglesey intermediate and Sunbiggin Tarn the shortest.

Table 5.5. Character comparison between known *Dactylorhiza purpurella* (3 populations) and *D. praetermissa* (2 populations) using ANOVA or Welch's test. Means followed by the same letter are not significantly different at 0.05 level. Letter A allocated to the longest measurement. Letters in bold indicate significant difference for the variable.

Dactylorhiza species	Population	Stat	Plant height /mm	Leaf width /mm	Leaf length /mm	Total bract length /mm	Bract beyond flower /mm	Lip width /mm	Lip length /mm	Spur length /mm	Inflorescence height /mm
D. purpurella	All combined	Mean	197.69 **B**	22.12 A	74.49 **B**	19.51 **B**	6.68 **B**	8.17 **B**	6.41 **B**	8.39 A	53.00 **B**
		St. Dev	58.97	5.81	16.41	3.88	2.78	1.13	0.82	1.07	13.05
D. praetermissa	All combined	Mean	324.56 **A**	21.27 A	122.71 **A**	27.64 **A**	14.32 **A**	9.65 **A**	8.40 **A**	8.48 A	66.93 **A**
		Std dev	75.99	4.35	22.18	6.61	6.23	1.59	1.08	1.25	17.37

The biometrics of the known populations of *D. purpurella* and *D. praetermissa* were further analysed by Principal Components Analysis (PCA) using the seven variables significantly different between samples (Table 5.5, Figure 5.3). The plot of principal component 1 (PC1) along the component 1 axis against principal component 2 (PC2) showed the taller *D. praetermissa* towards the high end of the component 1 axis, however it did not separate from *D. purpurella* along this axis. A few of the Farlington specimens (*D. praetermissa,* Southern Marsh-orchid) overlap with some of the Orton specimens (*D. purpurella,* Northern Marsh-orchid). Both species overlapped completely on PC2; *D. praetermissa* presented the wider range of scores (Figure 5.3).

The first component accounted for 68.2% of the variation, the second component for 9.7%. Main weightings along component 1 axis were Bract beyond flower, Plant height and Total bract length (all positive); along component 2 axis main weightings were Inflorescence length (positive) and Lip length (negative). Although there were significant differences in means for seven variables between *D. purpurella* and *D.*

praetermissa, the overall variation within samples led to overlap on the PCA plot (Table 5.5, Figure 5.3).

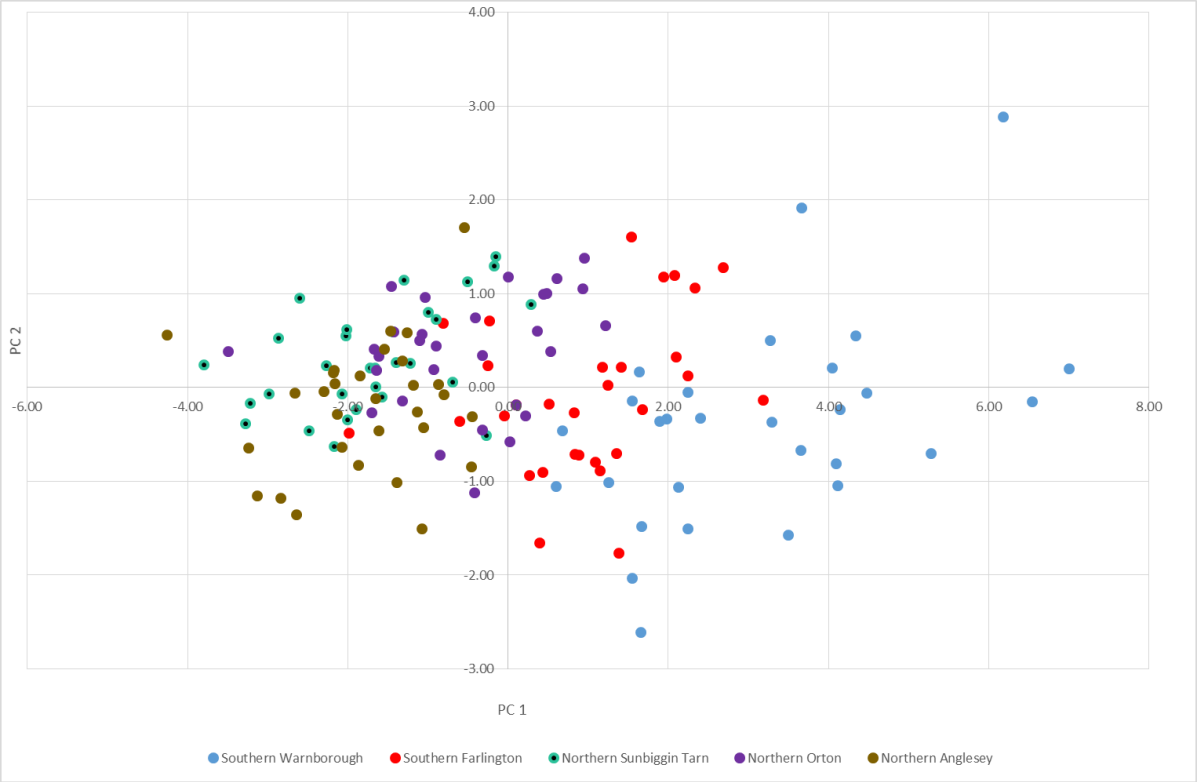

Figure 5.3. PCA comparing known *D. purpurella* (3 populations) and *D. praetermissa* (2 populations) using the seven variables shown to have significant differences between these two species. PC1 accounted for 68.2% of the variation, PC2 for 9.7%

Question 3. Are there differences between *D. purpurella*, *D. praetermissa* and Wigan Marsh-orchids for the same variables?

After excluding the Wigan Cemetery population from the Wigan Marsh-orchid group, the remaining three Wigan Marsh-orchid samples were tested for differences by ANOVA or Welch's test (Table 5.6). *Post hoc* tests showed that there were no significant differences between samples for three variables (Leaf length and width,

Excess bract beyond flower). No population was consistently taller / longer or smaller / narrower. The sample means for Wigan Flashes and Nob End were higher than sample mean for Bedford Colliery for most variables; the exceptions were Lip length and Spur length for which the Bedford Colliery sample was intermediate. This indicated that the three populations were similar and of the same parental origin. The samples were amalgamated as the Wigan Marsh-orchids sample for further analysis.

Table 5.6. ANOVA or Welch's test investigating the measured characters for potential hybrid Wigan Marsh Orchid populations. Means followed by the same letter are not significantly different at 0.05 level. Letter A allocated to the longest measurement. Letters in bold indicate significant difference for the variable.

Dactylorhiza species	Population	Stat	Plant height /mm	Leaf width /mm	Leaf length /mm	Total bract length /mm	Bract beyond flower /mm	Lip width /mm	Lip length /mm	Spur length /mm	Inflorescence height /mm
Wigan Marsh orchid	Wigan Flashes	Mean	241.26 **A**	27.06 A	108.82 A	27.87 **A**	10.10 A	8.35 **AB**	7.55 **A**	7.23 **B**	77.79 **A**
		St. Dev	71.01	7.24	23.71	5.03	5.14	1.39	0.99	0.92	23.18
Wigan Marsh orchid	Nob End	Mean	256.73 **A**	26.80 A	120.60 A	22.53 **B**	9.46 A	8.84 **A**	6.34 **B**	9.96 **A**	67.43 **AB**
		St. Dev	66.57	9.87	22.43	5.22	4.51	1.46	0.77	2.33	26.98
Wigan Marsh orchid	Bedford Colliery (Leigh)	Mean	195.30 **B**	23.53 A	116.40 A	21.39 **B**	8.52 A	7.56 **B**	6.72 **B**	7.95 **B**	60.37 **B**
		St. Dev	59.79	5.47	22.29	4.69	3.99	1.12	0.92	1.38	15.18

The Wigan Marsh-orchid group was then compared to *D. purpurella* and *D. praetermissa* samples (Table 5.7). The means for the Wigan research group were intermediate and significantly different from both the taller / wider *D. praetermissa* sample and the shorter / narrower *D. purpurella* for four variables: Plant height, Total bract length, Excess bract beyond flower and Lip length. The Wigan research sample means for leaf length, lip width and spur length were also intermediate between the other two samples, but not significantly different from one other sample. The Wigan research sample had the highest mean for only two variables: inflorescence height and leaf width, however only the leaf width mean was significantly different from both *D. purpurella* and *D. praetermissa* samples (Table 5.7). This indicated that generally the Wigan research sample was an orchid intermediate in size between *D. purpurella* and *D. praetermissa* for the variables measured.

Table 5.7. Character comparison between known populations of *Dactylorhiza purpurella, D. praetermissa* and the populations of Wigan Marsh Orchids using ANOVA or Welch's test. Means followed by the same letter are not significantly different at 0.05 level. Letter A allocated to the longest measurement. Letters in bold indicate significant difference for the variable.

Dactylorhiza species	Population	Stat	Plant height /mm	Leaf width /mm	Leaf length /mm	Total bract length /mm	Bract beyond flower /mm	Lip width /mm	Lip length /mm	Spur length /mm	Inflorescence height /mm
D. purpurella	All combined	Mean	197.69 **C**	22.12 **B**	74.49 **B**	19.51 **C**	6.68 **C**	8.17 **B**	6.41 **C**	8.39 A	53.00 **B**
		St. Dev	58.97	5.81	16.41	3.88	2.78	1.13	0.82	1.07	13.05
D. praetermissa	All combined	Mean	324.56 **A**	21.27 **B**	122.71 **A**	27.64 **A**	14.32 **A**	9.65 **A**	8.40 **A**	8.48 A	66.93 **A**
		Std dev	75.99	4.35	22.18	6.61	6.23	1.59	1.08	1.25	17.37
Wigan research	All combined	Mean	231.53 **B**	25.85 **A**	115.00 **A**	24.10 **B**	9.39 **B**	8.25 **B**	6.90 **B**	8.33 A	68.93 **A**
		Std dev	70.35	7.80	23.15	5.72	4.59	1.42	1.03	1.98	23.29

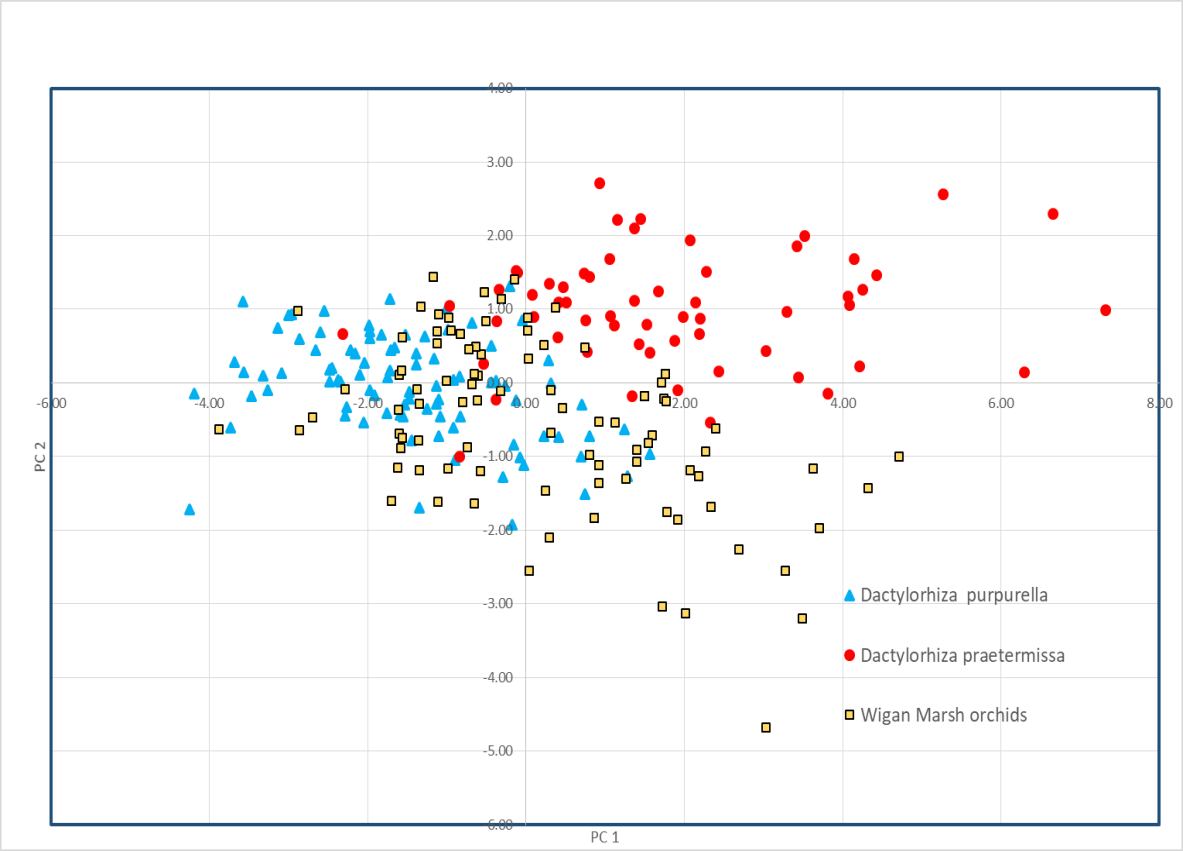

Figure 5.4. PCA of *Dactylorhiza purpurella, D. praetermissa* and the Research Population of Wigan Marsh-orchids, using the eight significant variables. This excludes the Wigan cemetery population due to the apparent affinity with *D. praetermissa*. PC1 accounted for 53.6% of the variation and PC2 for 14.8%.

The first component of Fig 5.4 accounted for 53.6% of the variation and the second component for 14.8%. Highest weightings for component 1 were Total bract length, Excess bract beyond flower and Plant height (all positive). *D. praetermissa* did not separate from the other taxa along any single axis but was more or less separated from the other two taxa by a combination of high axis 1 and high axis 2 scores. There are eight *D. praetermissa* individuals with negative axis 1 scores which are located amongst the clusters of the other two taxa. *D. purpurella* was positioned on the negative end of axis 1. *D. purpurella* with positive axis 1 scores tended to have low (negative) axis 2 scores and are thus separated from *D. praetermissa*.

The Wigan Marsh-orchid sample presented a wide range along both axes and overlapped considerably with *D. purpurella*. However, similar to *D. purpurella*, Wigan Marsh-orchid specimens with positive axis 2 scores tended to have low (negative) axis 1 scores and this presented some separation from *D. praetermissa*. Although the Wigan research sample had intermediate means for these three variables (Table 5.7), the PCA placed this group more or less completely overlapping *D. purpurella*, and partially overlapping of lower-scoring (axis 2) *D. praetermissa* specimens (Figure 5.4). Highest weightings for component 2 were Leaf width (negative), Lip length (positive) and Inflorescence length (negative). Wigan Marsh-orchid specimens had widest leaves (negative weighting) and this would contribute to the low position of some of this group on the component 2 axis. In contrast, *D. praetermissa* specimens had the longest Lip lengths and that would position specimens in higher positions on this axis (Table 5.7, Figure 5.4).

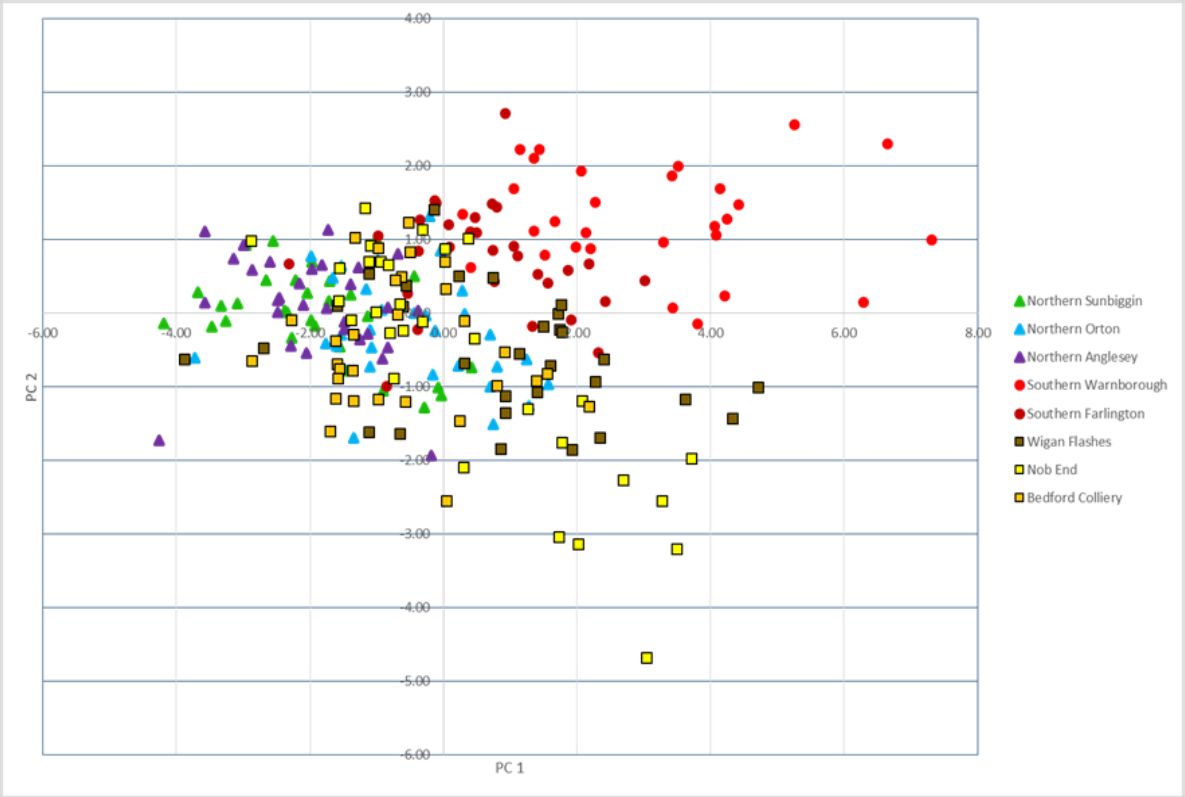

Figure 5.5. PCA of *Dactylorhiza purpurella* (Northern Marsh), *D. praetermissa* (Southern Marsh) and Wigan Marsh orchids showing populations, using the eight significant variables, comparing differences at each of the surveyed sites. PC1 accounted for 55.6% of the variation and PC2 for 18.2%.

Examination of the results of PCA at population level revealed some clustering by population (Figure 5.5). The Warnborough Greens population of *D. praetermissa* (bright red circles) presented the highest x and y scores for the taxa and were quite widely spread, whereas Farlington specimens (maroon circles) were more tightly clustered. The Sunbiggin Tarn (green triangles) and Anglesey (purple triangles) populations of *D. purpurella* formed clusters with negative x scores and overlap more or less completely. The Orton population (blue triangles) presented a combination of negative and positive x scores, partially overlapping the other two *D. purpurella* populations. Along the component 1 axis, Orton (*D. purpurella*) was the population partially overlapping with Farlington specimens (*D. praetermissa*).

The research samples of Wigan Marsh-orchid did not present tight population clusters, but were very scattered with outliers. Both Wigan Flashes and Nob End samples presented a few specimens with high axis 1 / axis 2 combination (Figure 5.5). Wigan Flashes also had two specimens with very low axis1 scores. Nob End presented eight scattered outliers with low axis 2 scores, but also presented a cluster of specimens with component 1 scores just less than zero and fairly high component 2 scores. Bedford Colliery (Leigh) is spread widely along the NW-SE axis. The variability of the Wigan populations shown in Figure 5.5 is in contrast to ANOVA / Welch's test (Table 5.6) which indicated similarities between populations.

However, the PCA scores and AVOVA / Welch's test results for the Wigan research populations can be at least partly explained. The Wigan samples were very variable as shown by the large standard deviations (Table 5.6). Therefore, there were individual specimens that presented a suite of variables that positioned them as outliers. For example, both Wigan Flashes and Nob End have higher means than Bedford Colliery for the variables showing the highest weightings for component 1 (Total bract length, Excess bract beyond flower and Plant height). Therefore a few specimens from these two locations would have been tall with long bracts and be positioned as high scoring outliers on the component 1 axis. The low-scoring Nob End outliers on the component 2 axis would be those with short Lip length, wider leaves and longer inflorescences (Table 5.6).

To summarise, the PCA plot did not place Wigan Marsh-orchid in the intermediate position between the two suggested parental taxa, but presented a more complex picture of variability within and between populations.

Question 4. Does the population from Wigan Cemetery show affinity with *D. praetermissa?*

The Wigan Cemetery sample was shown to be different and taller / wider than the other Wigan Marsh-orchid populations (Table 5.4) and therefore was more similar to the taller *D. praetermissa*. To further investigate the affinities of this population, sample means for the Wigan Cemetery sample were compared to means the two *D. praetermissa* samples using ANOVA or Welch's test (Table 5.8). This showed that the Wigan Cemetery sample was not significantly different from at least one of the two *D. praetermissa* samples for seven out of the nine variables. All three samples had significantly different means for Excess Bract beyond flower, with Wigan Cemetery in the intermediate position. For the ninth variable, leaf length, Wigan Cemetery was significantly taller than both *D. praetermiss*a samples.

Table 5.8. ANOVA or Welch's test for *Dactylorhiza praetermissa* and Wigan Cemetery research Marsh Orchid population investigating the similarity of these taxa based on the measured characters. Means for the same character followed by the same letter are not significantly different at 0.05 level. Letter A allocated to the longest measurement. Letters in bold indicate significant difference for the variable.

Dactylorhiza species	Population	Stat	Plant height /mm	Leaf width /mm	Leaf length /mm	Total bract length /mm	Bract beyond flower /mm	Lip width /mm	Lip length /mm	Spur length /mm	Inflorescence height /mm
D. praetermissa	Warnborough Green	Mean	358.62 **A**	23.79 **A**	125.41 **B**	32.07 **A**	18.67 **A**	10.62 **A**	8.86 **A**	8.24 A	65.52 A
		St. Dev	83.58	3.76	19.74	6.16	5.91	1.61	0.96	1.33	19.33
D. praetermissa	Farlington Marsh	Mean	291.63 **B**	18.83 **B**	120.10 **B**	23.35 **B**	10.11 **C**	8.72 **B**	7.95 **B**	8.72 A	68.30 A
		St. Dev	50.23	3.41	24.36	3.46	2.58	0.85	1.01	1.13	15.46
Wigan Marsh orchid	Wigan Cemetery	Mean	325.72 **AB**	25.52 **A**	156.03 **A**	25.95 **B**	14.04 **B**	8.91 **B**	8.29 **AB**	8.38 A	67.53 A
		St. Dev	66.09	6.10	37.64	5.24	4.69	1.61	1.17	1.30	17.29

This indicated that the Wigan Cemetery population bears a strong similarity to *D. praetermissa* for the nine variables measured. Coupled with the relatively undisturbed habitat (see results for question 1 above), this suggested the identity of this population is *D. praetermissa* or close to this taxon.

5.5. Discussion

The four studied populations of Marsh-orchids from the Wigan area appeared to form two morphological groups and these groups are related to time since anthropogenic disturbance. The Wigan Cemetery population, which is on ancient grassland, bore a close resemblance to *D. praetermissa* for the characters studied (Table 5.8). The other three populations 'Wigan Marsh-orchid': Wigan Flashes, Nob End and Bedford Colliery are all found on reclaimed land that has been modified from coal-mining waste and, as a group, they presented biometric similarities when sample means were compared (Table 5.6). However, this masked the wide ranges for some variables measured and concealed some unusual specimens. PCA analysis, revealed wide intra- and inter-sample variation when Wigan Marsh-orchid was analysed with the potential parental taxa, *D. purpurella* and *D. praetermissa* (Figures 5.4, 5.5).

The cemetery population growing shows distinctive and significant differences to the three growing in the same geographical area but on synanthropic soils (Wigan Flashes, Bedford Colliery and Nob End). In contrast, the Wigan Cemetery population is within a long-established grassland in an area of the cemetery used in the mid-nineteenth century. Hence the cemetery plants are growing on soils which have developed for over a century, more than double the time for soil development in the synanthropic habitats.

It is possible that, although 'Wigan Marsh-orchid' from different sites appear superficially similar, the populations consist of hybrid swarms. Therefore, there could be F_1 and later generations, backcrosses, introgressed specimens and those presenting hybrid vigour or novel characters. This could explain the variability shown in the multivariate analysis.

The suggested parental species, *D. purpurella* and *D. praetermissa*, which are near the northern and southern limits, respectively, of their ranges of distribution in Britain, were also very variable. Although there were significant differences between sample means, they could not be separated by multivariate analysis (PCA) (Table 5.5, Figure 5.3). In this situation, trying to use the same technique to identify hybrids between these two taxa is unlikely to be successful. The Wigan Marsh-orchid sample presented intermediate means (Table 5.7) but was very variable and the PCA analysis presented complex overlap between Wigan and potential parents (Figures 5.4, 5.5). It is possible that other *Dactylorhiza* taxa have been involved in the history of Wigan Marsh-orchid.

The samples used in PCA analyses were not of equal sizes, a factor that may compromise results as larger samples can drive the analysis (Hair *et al.,* 1998). However, the great variability found within Wigan Marsh-orchid, and revealed by PCA (Figures 5.4, 5.5), is not best suited for this technique as the variability is spread across all the variables, not restricted to a subset of the variables.

The Marsh-orchids are one of the Northwest's most frequent orchids, occurring in large populations in the wet marshes of the coastal strip and the fens and marshes of the synanthropic habitats around Wigan and Bolton (Preston *et al*., 2002). However, widespread undermanagement of many of the grasslands led them to become coarse rank vegetation and led to a decline of many of the orchid populations in this landscape. These factors drastically reduce the number of favourable habitats remaining for these species (Shaw, 2009).

If the soil type is suitable and conditions are damp, the Marsh-orchids can sometimes rapidly re-colonise formerly disturbed or cultivated ground. There are twelve such locations in the Wigan area (GMEU, *pers. comm*.) where these orchids now occur on former coal mines and other post-industrial synanthropic land. Here is the zone of overlap between the ranges of Northern *D. purpurella* and Southern Marsh-orchid *D. praetermissa* (Stace, 2015). Given that *D. purpurella* is restricted to four Northern European countries (Denmark, Ireland, Norway and UK; WCSP, 2016), the zone where it meets the more widespread (on a European scale) *D. praetermissa* is of particular interest. Within this zone it appears that synanthropic sites are providing habitats for regionally rare or localised taxa especially in urbanized areas (Shaw 1997; Shaw, 2011). The disturbed ground provides opportunities for taxa to colonise that are able to cope with the novel conditions and these often include hybrids and non–native species (van Andel; 1987). The combination of geography and history may be unique with the Wigan area having given rise to a range of distinct gene flow opportunities not found in the more natural undisturbed habitats.

This gives conservationists the option to conserve an area of dynamic genetic flow and to maintain the local diversity in these orchid species, thus adopting the approach proposed by Ennos *et al.* (2005). By conserving areas of integration and potential hybridisation along with the named taxa, conservationists recognise the biological complexity of the situation. Conserving and giving opportunities to locally adapted lineages. In the case of *Dactylorhiza* efforts should be given to preserving the parental lineages, conservation of habitats where the allotetraploids flourish in the British Isles would then allow this dynamic process to continue. The patterns occurring in the allotetraploids have been characterised in genetic studies (Hedrén, 2003). Studies of

populations should allow the identification of lineages functioning as evolutionary units thus aiding the decision making process relating to the conservation of these plants and allowing further developments in taxonomy (Fay *et al.,* 2001).

Currently, site managers carry out traditional management techniques, such as hay cutting and grazing of grassland, to conserve the orchid diversity. The orchids are affected by human-induced changes to environments, including deforestation, urbanization, agricultural change and more recently, climate change, the influence of these factors is complicated by the requirement of orchid species rely on a complex interactions with other organisms for their survival (Fay, 2015).

It has already been shown by researchers that many taxonomic questions within *Dactylorhiza* cannot be solved by morphometric techniques alone and molecular techniques are required (e.g. Fay & Chase, 2001; Devos *et al.,* 2006; Hedrén *et al*., 2007). Future work looking at the relationships should aim to use both morphometric measurements and DNA based techniques to explore whether the phenotypic variability of these plants and the apparent hybrids are matched by appropriate lineages in their genetic variability. Such studies would develop a wider understanding of relationships and that will help conservationists set priorities for this group of plants.

5.6. References

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Chapter 6 - Summary

6.1. Introduction

This study, based around the Wigan Flashes, Wigan Greenheart and, latterly, the Great Manchester Wetlands, has investigated the impact of conservation management upon the synanthropic, post-industrial landscape. Over the last 200 years the pre-mining landscape of wet grassland and lowland raised bog has been markedly altered, producing a mosaic of habitats, including open water, reedbed, scrub, woodland, and grassland.

Within the last two decades, the work in the area has progressed from single-site-based conservation projects to a landscape-scale approach identified by the Great Manchester Wetlands NIA (Nature Improvement Area), via the earlier Wigan Council initiative, the Greenheart Regional Park. This development has been in line with the *Making Space for Nature* report (Lawton, 2010). The studies within this thesis have supported this development, particularly within Chapter 2 and Chapter 4 of this thesis.

The area within the study has been managed for conservation and the community by a partnership of conservation organisations, including the Lancashire Wildlife Trust and Wigan Council. A primary aim of the work is to manage the area to increase their nature conservation value. This has provided the opportunity to investigate conservation at various scales, within a post-industrial setting over a 16-year period. Conservation management of these habitats has revealed unique problems and equally unique opportunities. However, by using and adapting traditional and more

drastic land management techniques, the synanthropic landscape can deliver important regional, national and international conservation gains.

In particular, this thesis has provided evidence that the management of these synanthropic sites can provide nationally important conservation outcomes over a 16-year period, benefiting a range of habitats, species and communities. The development of the reedbeds and the meadows demonstrates the capacity of the post-industrial landscape to support communities of conservation value. Within the area Willow Tits are maintaining their populations set against a background of national decline, while the orchid study demonstrates the evolutionary potential of such sites. These studies are applicable to other areas in the UK which still has landscapes which are a relic of the industrial revolution, including South Wales, South Yorkshire and central Scotland. Across the globe such habitats are widespread. The findings of this study are applicable beyond the synanthropic areas of Britain. Comparable habitats with similar conservation issues exist in other parts of World (e.g Angers, France; Huaibei China, Ruhr, Germany). As countries seek to maintain biodiversity alongside increasing urbanisation and development the findings here have wider application, though the target species may be different. Conservation of such sites across the world could be enhanced through international collaboration of researchers and conservation practitioners, hence integrating research and conservation management.

6.2. Reedbeds

Chapter 2 investigated the potential value of the reedbeds within the Great Manchester Wetlands NIA in providing an interlinked habitat using the habitat requirements and dispersal distances of vertebrate and invertebrate reedbed specialists.

This approach came directly from the philosophy of the Lawton report (2010), but utilised available literature rather than the usual mathematical modelling approach. The total area of the habitat provides approximately 2% of all the freshwater reedbed resource in the UK (United Kingdom) and this provides key habitat for many species, demonstrating the value of reedbeds growing on post-industrial land. However, it remains unknown whether it is functioning as an interlinked landscape. While the majority of avifauna can move around the reedbed system, inter-site connectivity for non-avian vertebrates may be a challenge. For invertebrates, the dispersal ecology and habitat requirements are simply unknown. Simple but important follow on research would be to record the invertebrate species living in these reedbeds, to study their ecology and to assess the gene flow between sites using molecular methods.

6.3. Meadows

The restoration of the colliery shale in the Wigan Coalfield has provided opportunities to create new grasslands. The success of this restoration at producing an ecologically useful grassland was explored. After seeding with a ‘meadow style’ restoration mix the long-term continuity of management has allowed the development of an MG5 hay meadow, which has taken fifteen years to form a stable and identifiable grassland type. This study has shown the importance of targeting the outcome of the management

and steering the grassland development by the addition of Yellow Rattle, *Rhinanthus minor* L. and that the post-industrial nature of the sites has not prevented the meadows developing into recognisable NVC (National Vegetation Classification) communities. While these created meadows are a valid reservoir of biodiversity they do not replace those lost due to change in agricultural practices in the last 70 years.

The sites remain a useful research resource, worthy of continued botanical monitoring, as they continue to develop. Further research in these areas would be to assess the invertebrate community present and compare with long established meadows.

Due to the success in the development of the grassland meadows, the area under hay meadow conservation in Wigan Borough has increased from the seven hectares studied in the thesis to over 70ha. This makes the area one of the largest grassland restorations in the UK.

6.4. Willow Tits

With an apparently stable population and about 10% of the endemic race of Willow Tit (*Poecile montanus kleinschmidti* Conrad von Balderstein,1827), the borough of Wigan is an ideal location to study the habitat requirements of this species, particularly when set against the recognition that is the UK's fastest declining non-migratory bird.

The former collieries and heavy industry of the area have bequeathed a mosaic of wetland habitats, including wet scrub and woodland dominated by quick-growing species such as grey willow. The landscape, which is 65% greenspace, is linked by the wetlands and disused railways. These are the habitats used by the Willow Tits. It is suggested that the connectivity provided by the network of scrub habitats are a key factor in the continued success of willow tit in the area. Elsewhere in the north-west of England, among the rural parts of Cheshire and Lancashire, there is a markedly lower density of Willow Tit. The may be explained by the intensive agricultural land use and resultant absence of scrub within the landscape mosaic in these areas.

The future conservation of the species relies upon an understanding of how Willow Tit populations are maintained spatially on a landscape scale, including how they maintain populations within a local area. Currently, the species is the focus of a ‘Back from the Brink’ project that is trying to resolve these issues by using GIS (Geographic Information System) and resistance modelling across northern England. The work on willow tit in Wigan is being repeated across the country, with nesting opportunities being increased based on the work reported on in this thesis and earlier conservation of the species. The author is now on the Willow Tit working group, investigating the wider conservation of the species.

6.5. Orchids

The restored landscape and disturbed nature of the soil substrates has created a variety of dynamic edaphic conditions. These present a range of evolutionary opportunities for species that can rapidly adapt. It is these habitats that marsh orchids (*Dactylorhiza* spp*.)* have colonised. The north-west of England is also the zone of overlap between the ranges of Northern and Southern Marsh-orchid (*D. purpurella* (T and T.A. Stephenson) Soó and *D. praetermissa* (Druce) Soó*,* respectively). Moreover, the Wigan Flashes are known for the *Dactylorhiza* numbers, although they have always been difficult to assign to a species. This study used morphological methods to identify the composition of these populations by comparison with populations of *D. purpurella* and *D. praetermissa* from other parts of the UK, beyond the zone of hybridisation. The populations from synanthropic habitats proved highly variable and intermediate between *D. praetermissa* and *D. purpurella,* probably reflecting gene flow between the two species. By comparison, the Wigan population from ancient grassland, showed strong affinity to *D. praetermissa*. It is likely that the genetic diversity, and hence conservation of Wigan Marsh-orchid, is best served by continuing current management practices that allow gene flow to occur. A fuller picture of gene flow between the various species and locations could be established through the use of appropriate molecular markers (eg microsatellites) to supplement the understanding of the picture obtained by the morphological analysis undertaken here.

The conservation of the meadows, by hay cutting, has been coordinated to maintain the orchid diversity as well as develop a stable and recognisable hay meadow community. The conservation of the meadows has taken into account the genetic

microevolution likely to be occurring at such a site (Briggs, 2009), as the meadows have developed over the sixteen years of management. The colonisation of this dynamic habitat by a range of taxa including *Senecio* and *Salix* which are known for their hybrids and introgressants (Stace *et al,* 2015), suggests that other taxa are also in a state of evolutionary flux.

6.6. Future Directions

Throughout the period of management of the study area there has been a monitoring and survey programme to assess the impact of the work on the habitat quality and the key target species. Success has been measured against nationally recognised targets.

The effects of future changes in management upon habitats and the species need to be understood. Hence, it is urged that baseline surveys, prior to the introduction of management changes are conducted, followed by comparable post-management surveys. Monitoring a wide range of habitats and taxa will ensure the early detection of detrimental practices or positive outcomes. These should be undertaken across a range of taxa. Invertebrates, in particular, are a key group that have not been considered in detail in this study, reflecting a wider neglect in conservation research, beyond the charismatic groups, such as butterflies.

As climate changes progresses, there is no doubt that some species will be affected, though the extent of this change remain uncertain. Many species within the study have altered their range limits through twentieth century. Understanding climate-associated

species shifts can help guide conservation management. Managing the connectivity of habitats across the landscape will continue to be an important driver for conservation within the study area to ameliorate population isolation.

6.7. Concluding remarks

This study shows that synanthropic habitats can be managed to enhance biodiversity at landscape, community, species and evolutionary dynamic level and thus support widespread and uncommon species. Such sites also support a wider range of habitats and species then those studied here, including several rare species.

6.8. References

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